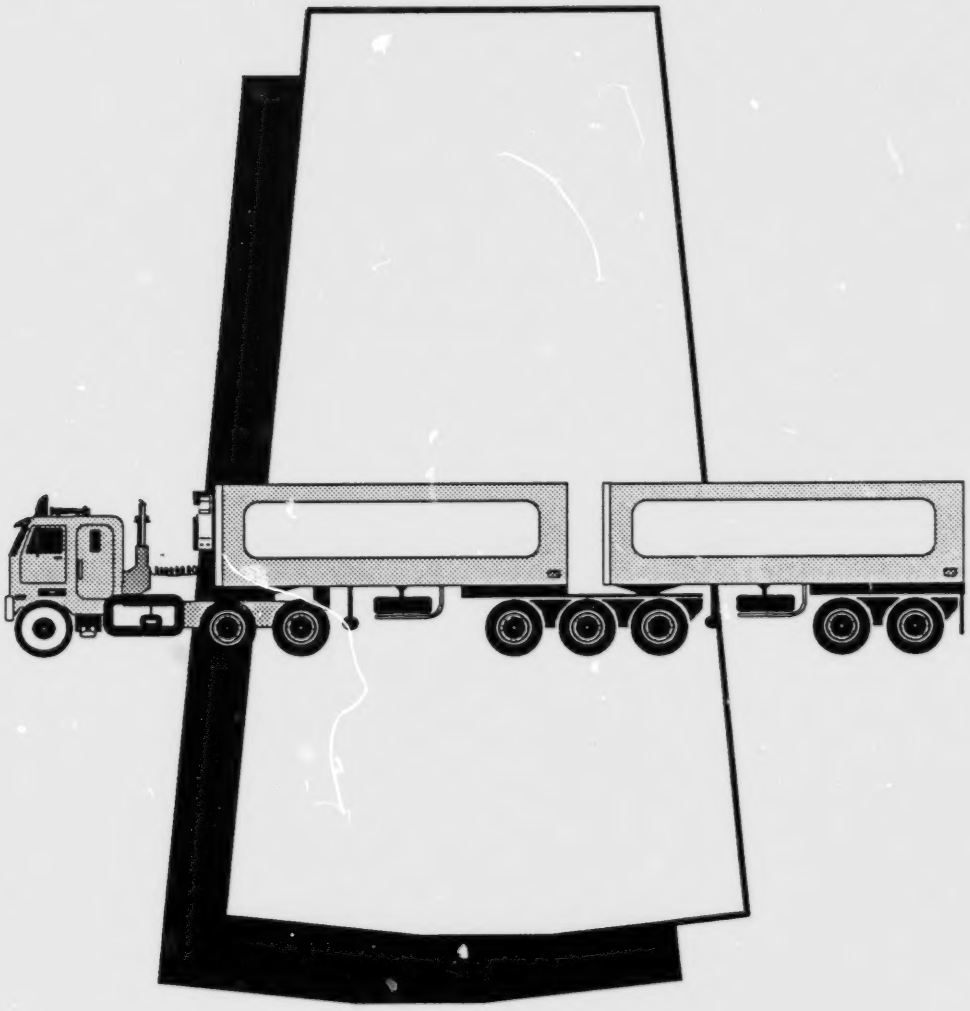
# THE SAFETY EXPERIENCE OF LARGE TRUCKS IN SASKATCHEWAN



Saskatchewan
Highways and
Transportation

# THE SAFETY EXPERIENCE OF LARGE TRUCKS IN SASKATCHEWAN

Prepared for

Saskatchewan Highways and Transportation
and
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## EXECUTIVE SUMMARY

The motoring public has perceptible concern about sharing the roadway with trucks. This public concern may be increasing because of the increased number of trucks using the highways, the increased size of trucks and the trend in recent years to smaller and lighter cars. We can anticipate that this public concern will continue to grow as the trend continues towards larger trucks and smaller cars.

Public debate on the safety of large trucks is highly emotional and often not founded on substantive fact. Issues of sharing the road with trucks and the safety of trucks often are confused. Part of the reason for the lack of factual discussion is the lack of detailed, well documented data and analysis.

Specifically, there is a need to understand more fully the safety performance of large trucks currently operating on public highways. This understanding is required if we are to work toward both increasing productivity and efficiency of the trucking industry and increasing truck safety.

To develop an improved data base and understanding of truck related accidents in Saskatchewan, Saskatchewan Highways and Transportation, with cost shared assistance from Transport Canada, implemented a project entitled "The Safety Experience of Large Trucks in Saskatchewan" in the spring of 1986. This study,

the results of which are reported herein, was conducted by the Transportation Centre at the University of Saskatchewan in association with the consulting firm of Clayton, Sparks & Associates Ltd. of Saskatoon.

There are three methods of analyzing the safety performance of large trucks, namely:

1) evaluation of vehicle performance under various situations on a test track,
2) computer simulation, and
3) the determination of actual over-the-road performance by calculating accident rates.

This investigation utilizes the method of determining over-the-road accident rates.

The specific objectives of the project were:

1. To quantify the number and type of accidents involving large trucks in Saskatchewan. Particular interest was to be directed toward the larger vehicles permitted under legislative changes in the past 15 years (i.e. double trailers in A, B, C-Train configurations).

2. To develop estimates of accident rates for large trucks operating in Saskatchewan.

3. To compare the accident experience of large trucks operating in Saskatchewan with the experience of other vehicle types in Saskatchewan and large trucks operating in other jurisdictions. This comparison was to provide a measure of the relative safety experience of large trucks in Saskatchewan.

4. To identify and quantify any safety related problem areas respecting large trucks operating in Saskatchewan.

Study Findings

Large trucks operating in Saskatchewan were involved in 947 reported accidents in 1985. Of these, 566 (60%) were in rural areas (provincial highways and rural roads) and 381 (40%) were within urban areas. Of the 947 accidents, 754 (80%) involved property damage of which 426 (56%) were in rural areas and 328 (44%) were in urban areas. There were 175 (18%) that involved injury (124, or 71% in rural areas; 51, or 29% in urban areas) and 18 (2%) that involved fatalities, of which 16 (89%) occurred in rural areas and 2 (11%) occurred in urban areas. Most of the serious accidents involving large trucks therefore occurred in rural areas (i.e. 71% involving injuries, and 89% involving fatalities).

In 1985, there were a total of 32,699 reported accidents in Saskatchewan involving 26,754 property damage accidents, 5,760 personal injury accidents, and 185 fatal accidents. Large trucks were therefore involved in 2.9% of all accidents, 2.8% of all property damage accidents, 3.04% of all injury accidents, and 9.7% of all fatal accidents. Large trucks represent about 0.62% of the total registered vehicles in Saskatchewan.

Large trucks were therefore involved in relatively few accidents in total number, but they were involved in a disproportionate number relative to their proportion in the total vehicle fleet. Further, they were involved in a disproportionately large number of the serious accidents, in particular, in rural areas. This finding is in accord with that of many previous studies undertaken for other jurisdictions.

Large trucks travel 5-10 times further per year than most other vehicles. As such, large trucks are more exposed to accidents than other vehicles. When the accident experience of large trucks was proportioned by exposure (i.e. distance travelled), it was found that large trucks operating in Saskatchewan experienced about the same number of accidents per million kilometres of highway travel as the vehicle population as a whole. For example, in 1986 the vehicle fleet as a whole in Saskatchewan experienced 0.81 reported accidents per million vehicle km of travel on provincial highways, while large trucks experienced an

estimated 0.713 reported accidents per million vehicle km of highway travel.

Further, the accident experience of large trucks operating on Saskatchewan provincial highways is approximately the same as large trucks operating on the interstate highway system in the USA (i.e. 0.76 accidents per million vehicle km of highway travel in the USA versus 0.713 in Saskatchewan).

The major contributing factors to accidents involving large trucks in Saskatchewan are human conditions (32%), i.e. driver inattention, driver distraction, had been drinking, driver inexperience, etc.; and environmental factors (40%), i.e. animal action, slippery surface, loose gravel, obstructed view, etc. Only about 35% of all accidents involving large trucks are in any way related to vehicle type, vehicle configuration or vehicle stability. Further, of those accidents where vehicle type, configuration or stability may be an issue, it is not clear that any particular type or configuration is always better than others.

This study identified only the initial cause of accidents. An accident can be initiated by driver inattention, animal action, slippery roads, actions by other drivers, etc. In some of these accidents, circumstances where vehicle type or configuration was not a parameter in the initial cause, vehicle type or configuration may have contributed to the type or severity of the

accident. This secondary effect is not reflected in the statistics presented herein.

The databases maintained by the Province of Saskatchewan do not include sufficient detail related to accidents and travel by vehicle type required in order to permit the determination of accident rates for specific types of large trucks (i.e. single trailer versus double trailer), or specific vehicle configuration (i.e. A-Trains versus B-Trains versus C-Trains). Therefore the operators of five large fleets were approached to provide details related to their accident experience with various types and configurations of large trucks.

These five fleets experienced a total of 718 accidents while travelling a total of 586 million vehicle km of travel throughout western Canada and the USA over the 1983-1986 period. It was found that <u>double trailer combinations experienced significantly less accidents per million vehicle km of travel than single trailer units</u>. This difference is likely attributable to different usage patterns, (i.e. road type), different driver skill and potentially different age of equipment as opposed to the differences in vehicle type. That is, single trailer units tend to be used more on rural and resource roads and secondary highways, tend to be driven by younger, less experienced personnel, and the equipment on average tends to be somewhat older. On the other hand, doubles are operated more on primary, divided highways by more experienced operators and the equipment

tends to be newer.

For double trailer units alone, the accident data from the five fleets indicate that B-Trains have fewer stability problems than either A or C-Trains. A and C-Trains do not display significant differences in their stability risks, but there is some evidence to suggest that C-Trains may result in more serious accidents than A-Trains.

Considerable difficulty was encountered during the course of the analysis with respect to determining statistically significant differences in accident rates for different vehicle types and configurations because of a problem with small sample size. If the differences in accident rates for different types of large trucks are small (and they usually are, i.e. 10-20%), then very large samples are required in order to detect statistically significant differences. To illustrate, if the actual difference in accident rate between two types of large trucks is in the order of 10-20%, then a sample size of 1-2 x $10^9$ vehicle km of truck travel is required in order to have a reasonable chance (85%) of detecting the differences and being reasonably confident (95%) that the differences are statistically significant. This suggests that only relatively large differences (i.e. >20%) in accident rates of large trucks of different types could be detected with samples available to the study. Indeed, this was the case as the sample size available herein was in the order of only 600 x $10^6$ million vehicle km. As such only relatively large

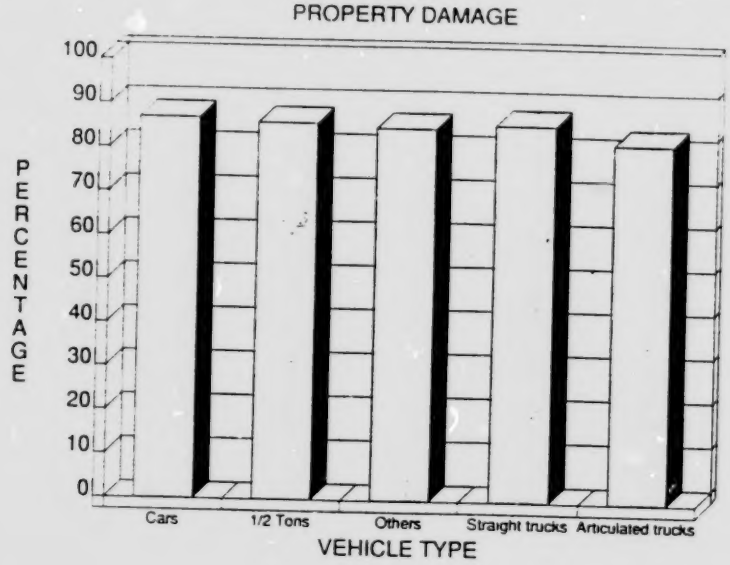
differences in accident rates could be detected (i.e. singles versus doubles, A and C-Trains versus B-Trains).

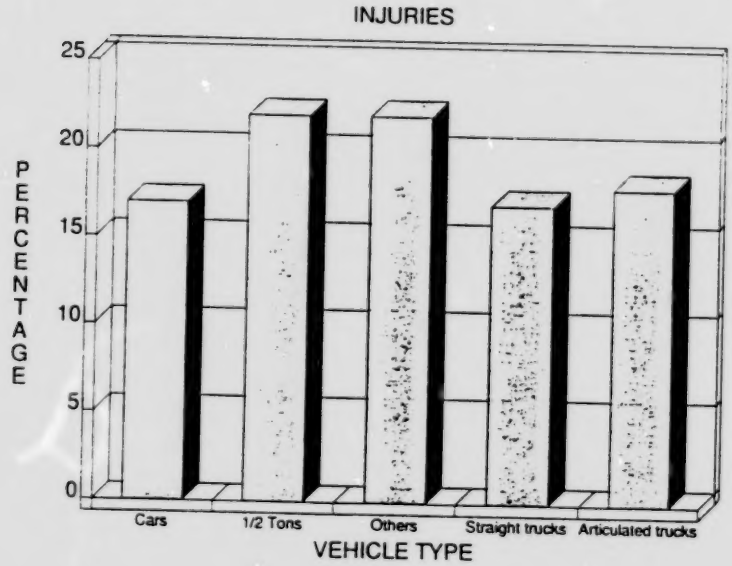
During the course of the study, there were no obvious major inadequacies identified related to the safety of large trucks operating in Saskatchewan. Most accidents involving large trucks, like accidents involving other types of vehicles, are caused by a complex combination of driver error or misjudgment, environmental conditions and chance circumstances. As such, there were no apparent "easy quick-fix" solutions to accidents involving large trucks. This is however not to suggest that continued vigilance is not required. Rather, it suggests that operators of the fleets which were the basis of this study take safety as a very serious matter, and as a result, have a safety record at least comparable to that of the vehicle population in total. Further, because of a job well done to date, future improvements in large truck safety are likely to be marginal improvements. That is, there are unlikely to be any ways identified to dramatically improve an already respectable safety record.

While this study focussed on developing accident rates for various vehicle types and configuration and did not specifically address stability issues per se other than via statistical analysis, in general, it was found that vehicle type and configuration played a much less important role in the overall accident experience of large trucks than generally perceived by

the public and transportation professionals. Safety, as it relates to large trucks, clearly cannot be equated to vehicle type and/or configuration. There are numerous other parameters like road, environmental, and driver that appear to play much more important roles relative to safety than the vehicle in general or vehicle type or configuration in particular. The area of driver training probably provides the most cost effective and productive target for truck safety policies and programs. This is not to suggest that complacency is appropriate with respect to the other major parameters (i.e. vehicle, road and environment).

FIGURE 3.6
SUMMARY OF PERCENT TOTAL VEHICLES INVOLVED IN REPORTED ACCIDENTS IN SASKATCHEWAN BY VEHICLE TYPE BY SEVERITY
1983-1986



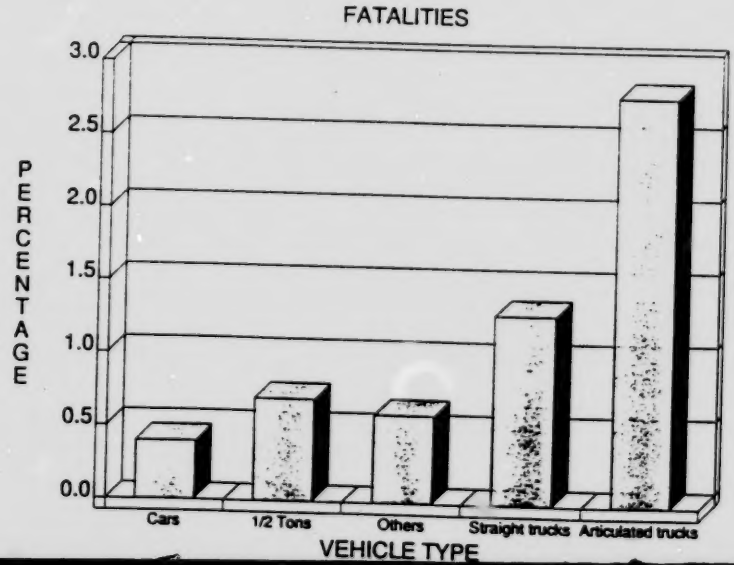



FIGURE 3.7
REPORTED ARTICULATED TRUCK ACCIDENTS
BY SEVERITY BY LOCATION IN SASK. (1985)

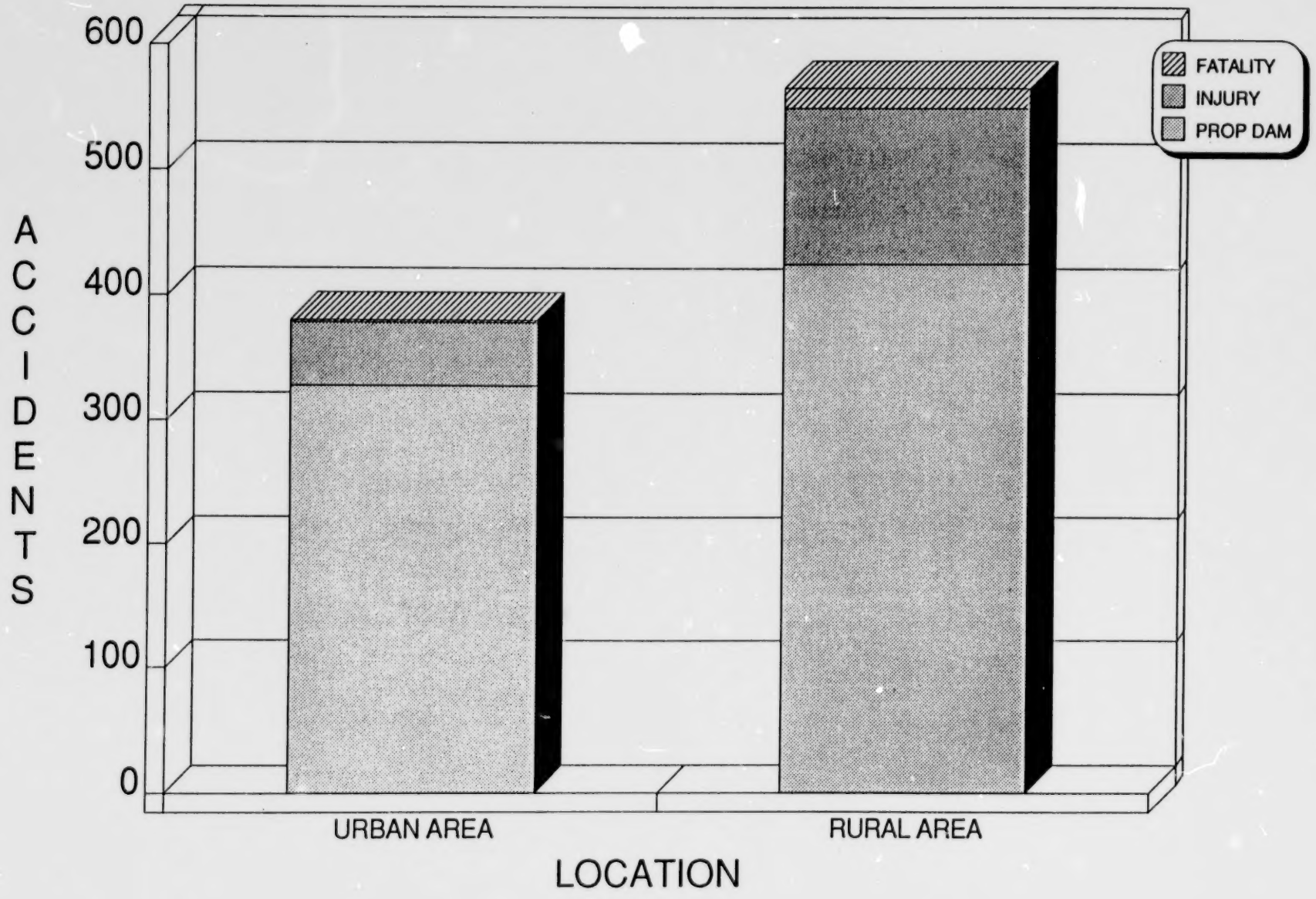


FIGURE 3.8
% OF ARTICULATED TRUCK ACCIDENTS
BY CONTRIBUTING FACTOR

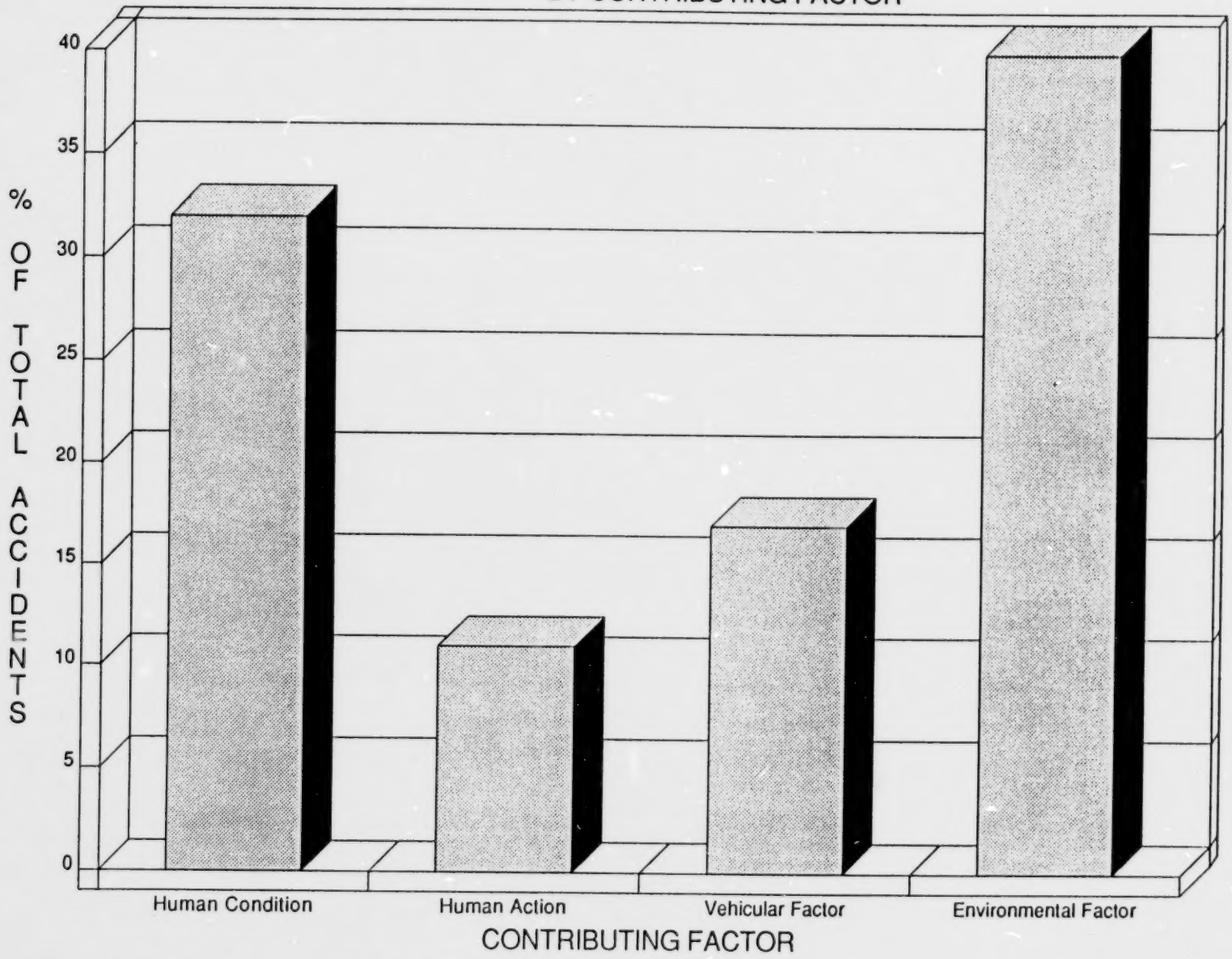
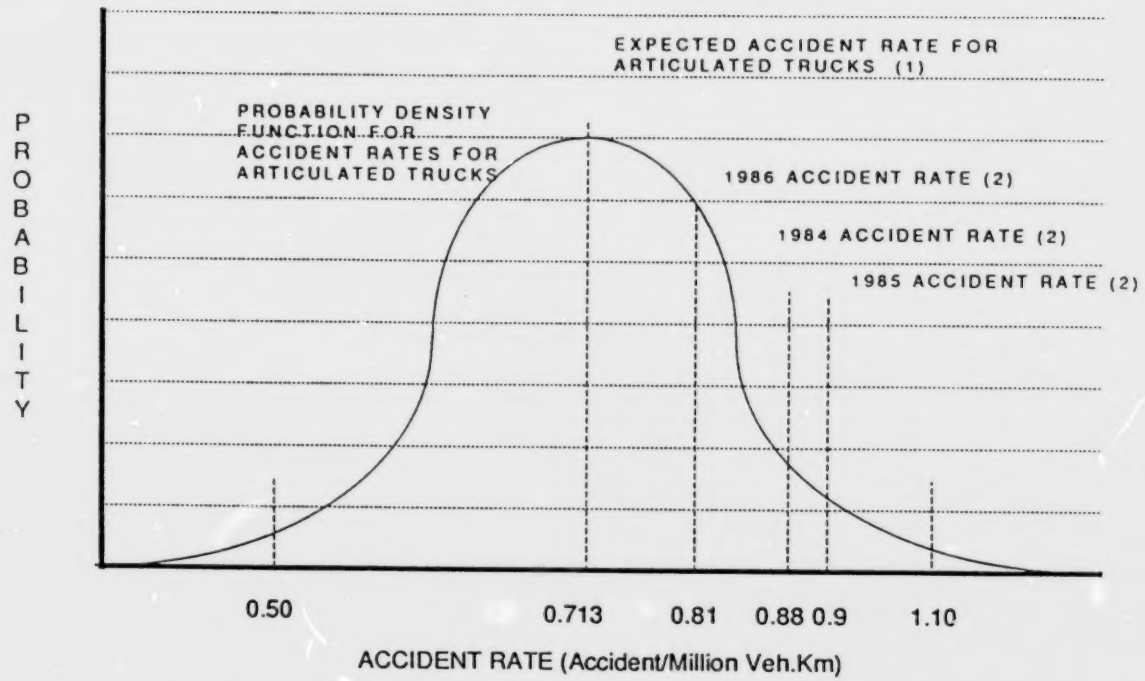


FIGURE 3.18

PROBABILITY DENSITY FUNCTION
ACCIDENT RATES FOR ARTICULATED TRUCKS
ON SASKATCHEWAN HIGHWAYS




(1) AS DETERMINED FROM THE PROBABILISTIC MODEL.

(2) ALL VEHICLES ON PROVINCIAL HIGHWAYS, ALL FATAL, INJURY AND PROPERTY DAMAGE ACCIDENTS INVOLVING DAMAGES OF GREATER THAN $500.

FIGURE 4.1
ACCIDENT EXPERIENCE OF 5 CARRIERS

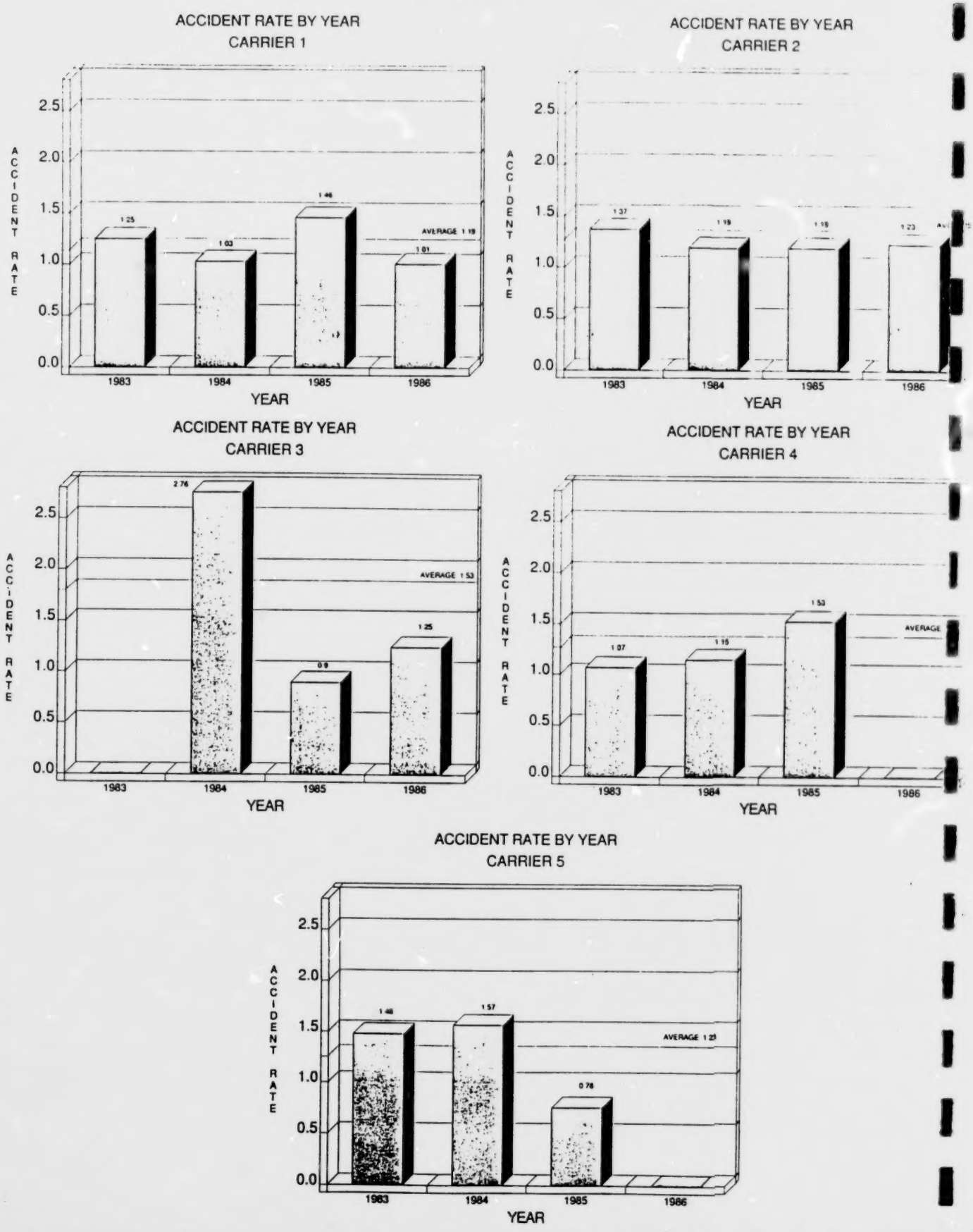


FIGURE 4.2
DISTRIBUTION OF ACCIDENT COST

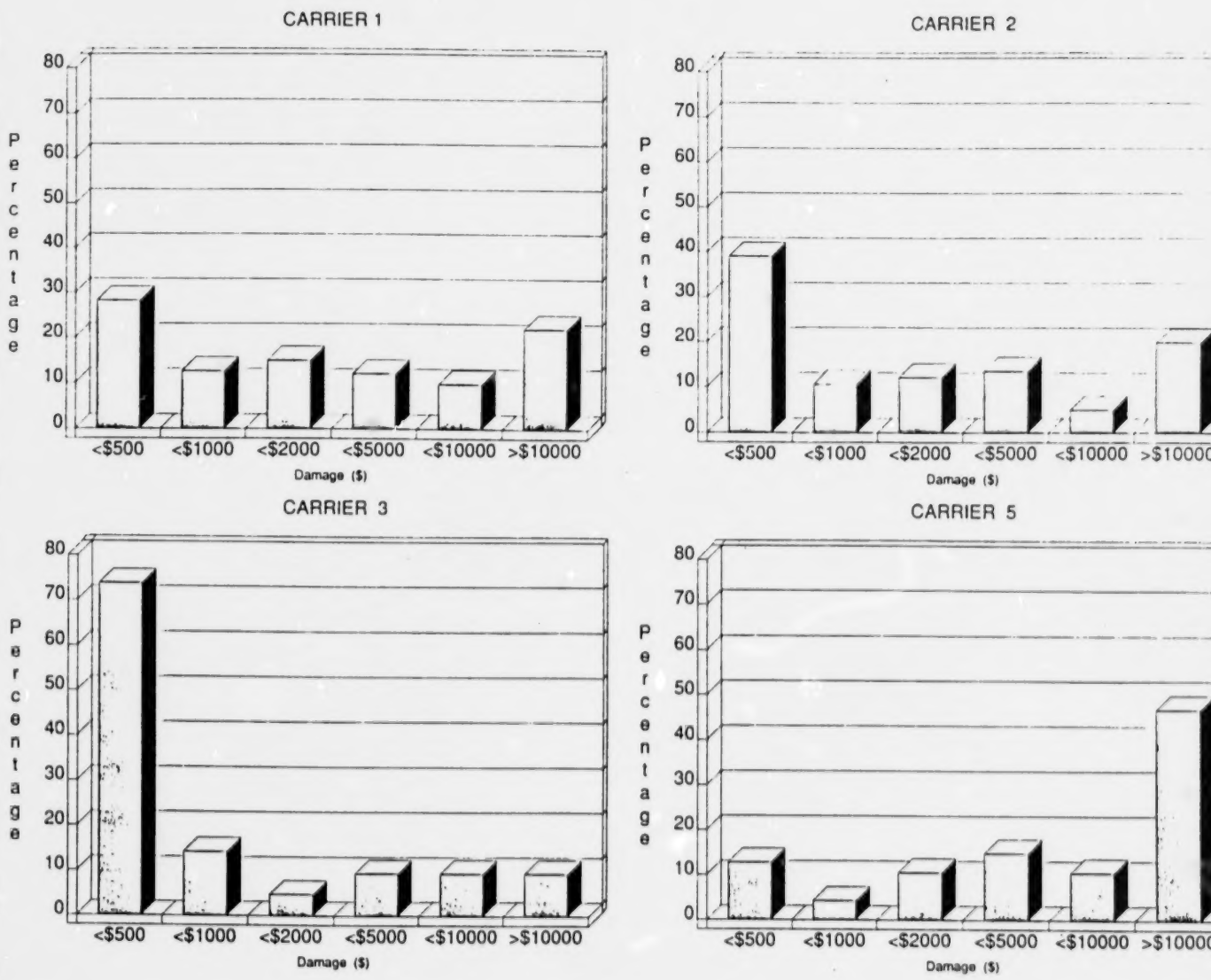
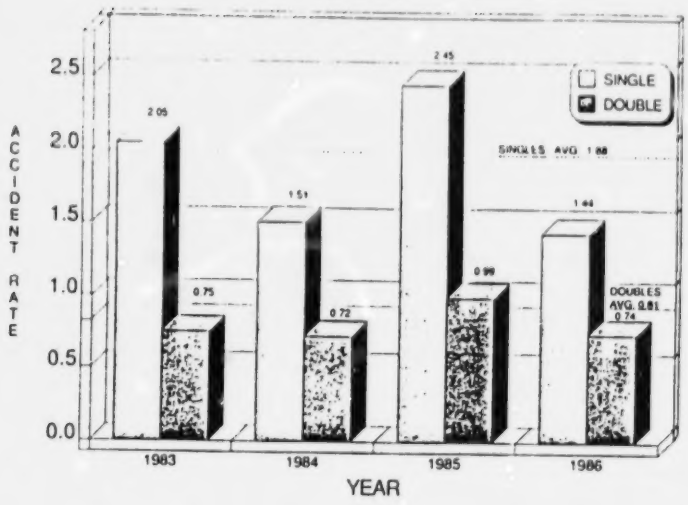
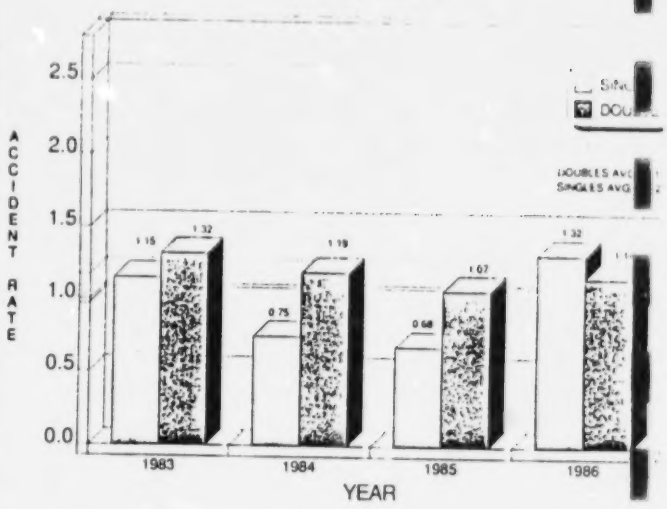


FIGURE 4.3
ACCIDENT RATE FOR
SINGLES VERSUS DOUBLES

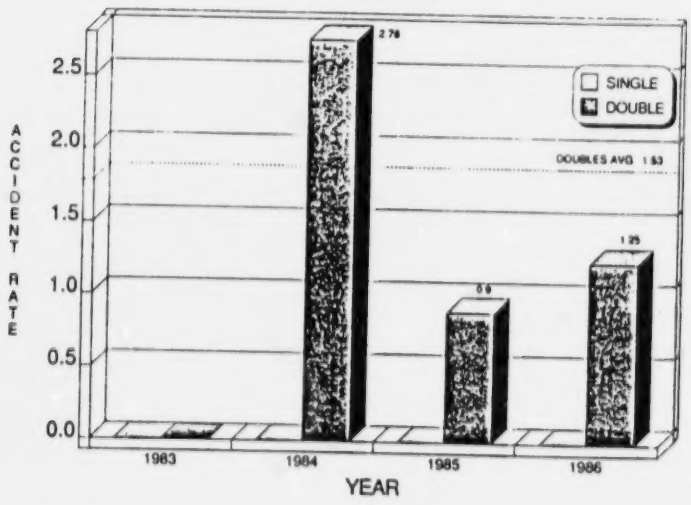
CARRIER 1



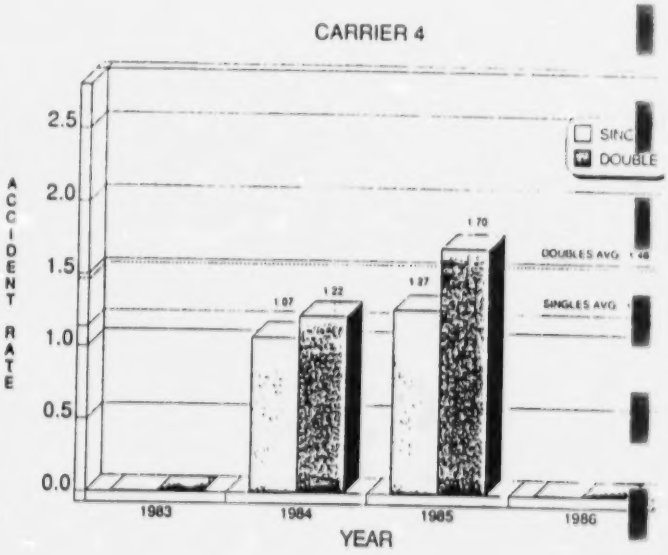

CARRIER 2




CARRIER 3




CARRIER 4




CARRIER 5

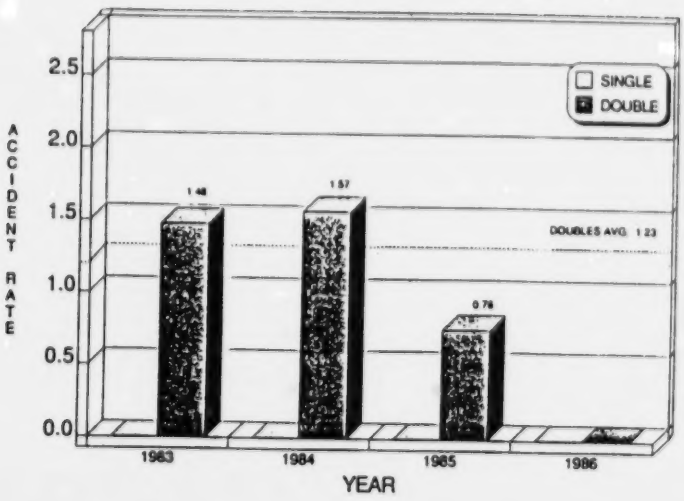
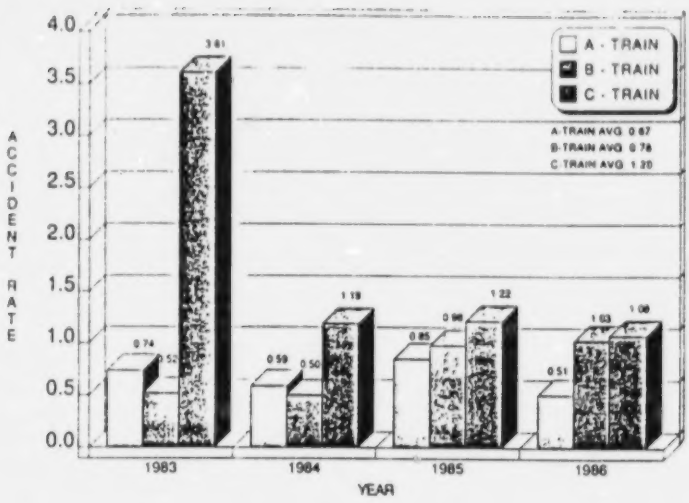
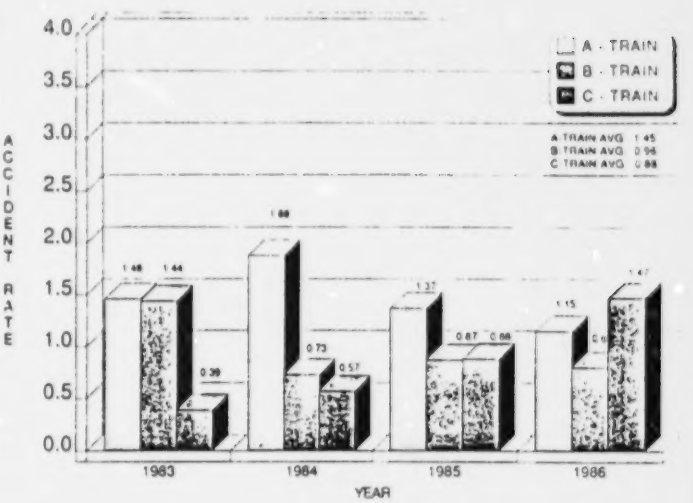


FIGURE 4.5
ACCIDENT RATES
BY VEHICLE CONFIGURATION

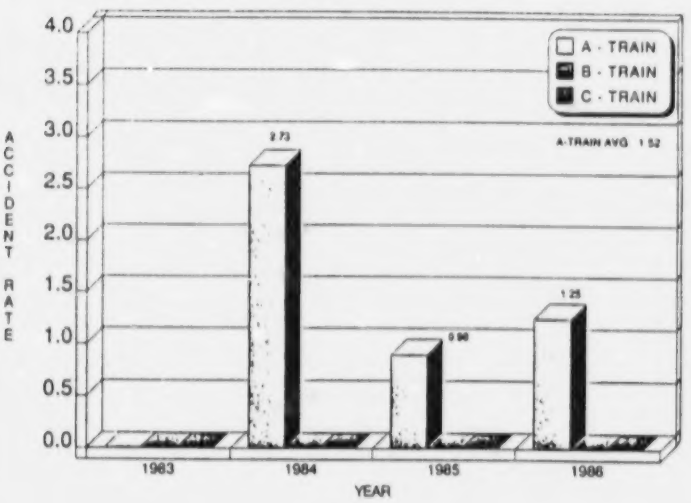
CARRIER 1




CARRIER 2




CARRIER 3

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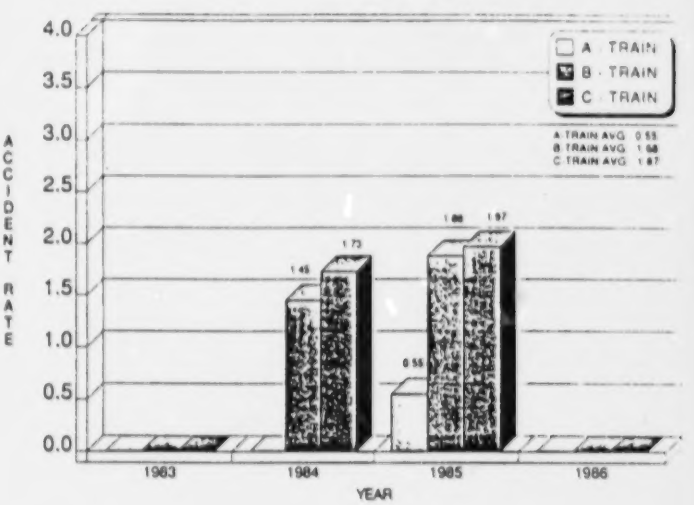


CARRIER 5

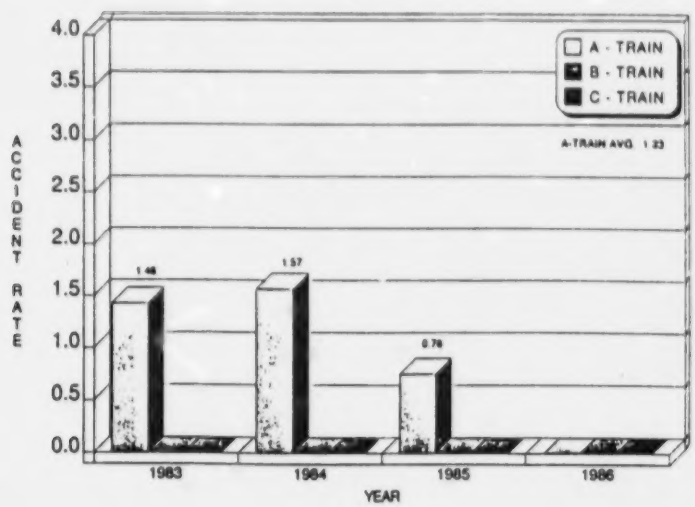

FIGURE 4.6
OVERALL ACCIDENT EXPERIENCE OF 5 FLEETS

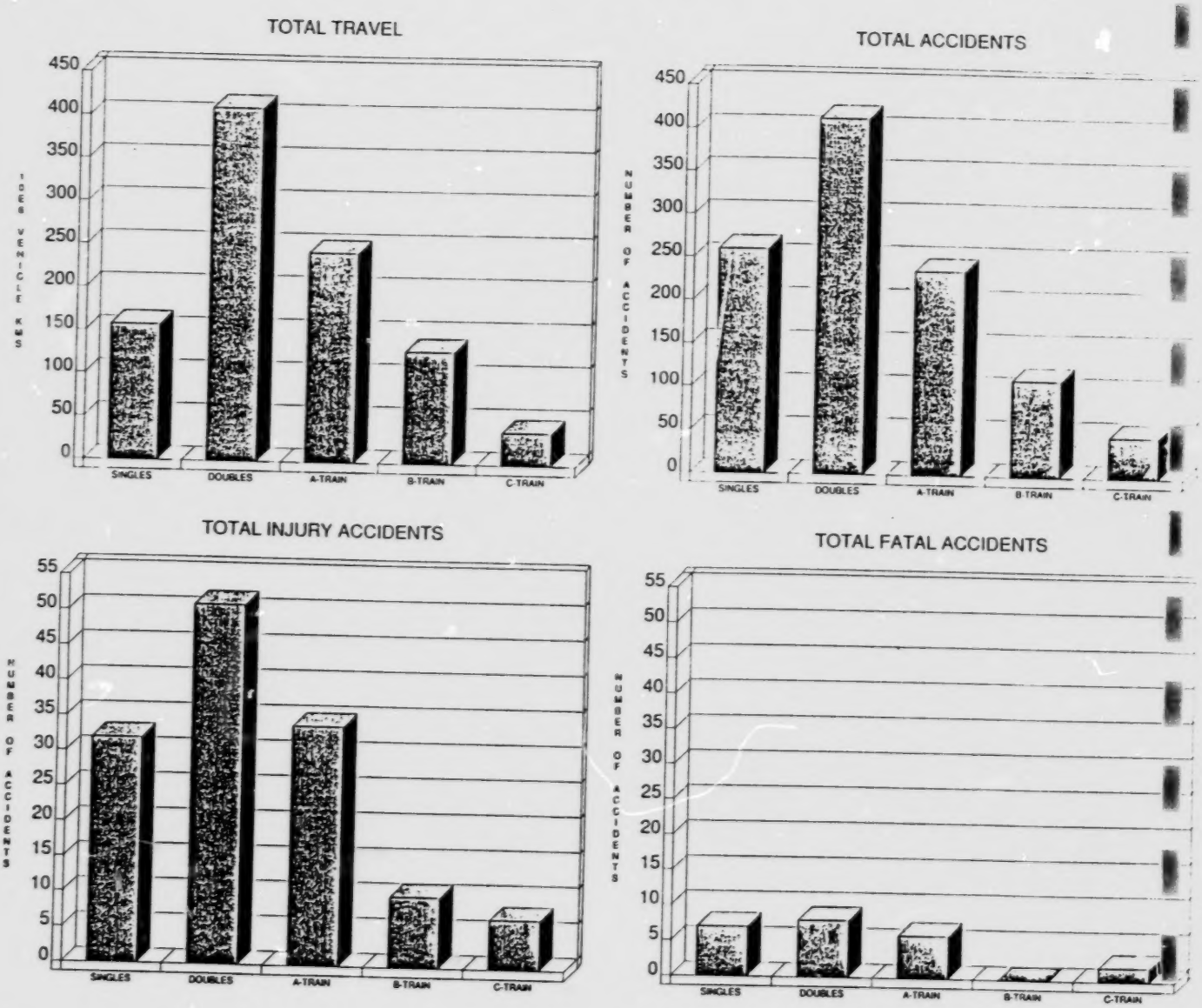

FIGURE 4.6
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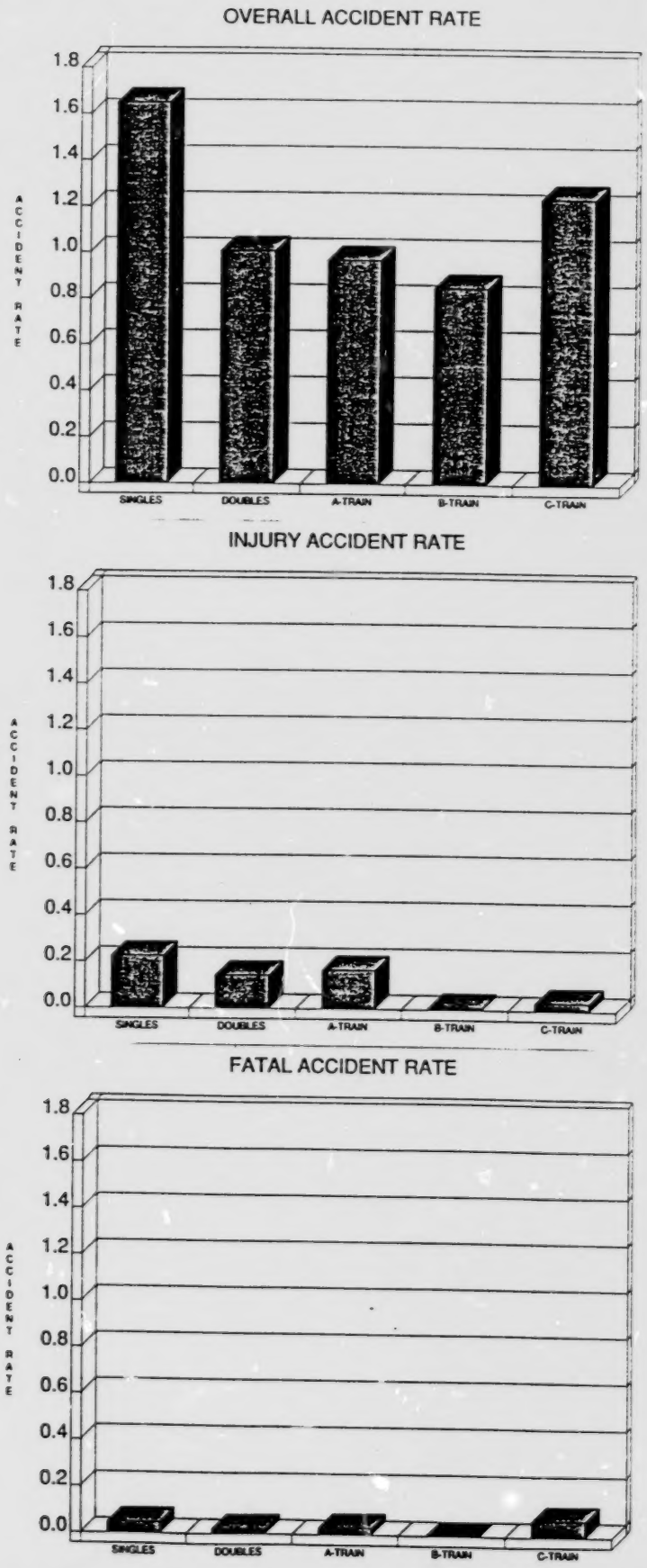


# Chapter 1: Introduction

## 1.1 Background

There is growing public concern about large truck safety. This is a result of the increasing number of trucks on the road, the increasing size of trucks, and the trend in recent years to smaller and lighter cars. It is anticipated that this public concern will continue to grow as the trend continues towards larger trucks and smaller cars.

Public debate on the safety of large trucks is highly emotional and often not founded on substantive fact. Part of the reason is the lack of detailed, well-documented data and analysis.

There is a need to understand more fully the safety performance of large trucks. This understanding is required if we are to work toward both increasing productivity and efficiency of the trucking industry and increasing truck safety.

To develop an improved data base and understanding of truck safety in Saskatchewan, Saskatchewan Highways and Transportation, with cost shared assistance from Transport Canada, implemented a project entitled "The Safety Experience of Large Trucks in Saskatchewan" in the spring of 1986. This study, the results of which are reported here, was conducted by the Transportation

Centre at the University of Saskatchewan in association with the consulting firm of Clayton, Sparks & Associates Ltd. of Saskatoon.

## 1.2 Objectives

The specific objectives of the project were:

1) To quantify the number and type of accidents involving large trucks in Saskatchewan. Particular interest was directed toward the larger vehicles permitted under legislative changes in the past 15 years (i.e. double trailers in A, B, C-Train configurations).

2) To develop estimates of accident rates for large trucks operating in Saskatchewan.

3) To compare the accident experience of large trucks operating in Saskatchewan with the experience of other vehicles in Saskatchewan and large trucks operating in other jurisdictions. This was to provide a measure of the relative safety experience of large trucks in Saskatchewan.

4) To identify and quantify any safety related problem areas respecting large trucks operating in Saskatchewan.

## 1.3 Methodology

In fulfilling the objectives noted above, a number of specific tasks were undertaken during the project. These were:

1) A review of available literature on accident experience of large trucks operating in other jurisdictions. The primary source of this information was published reports.

2) The development of a profile of the accident experience of large trucks operating in Saskatchewan using data available from: (1) The Traffic Accident Information System (TAIS) maintained by Saskatchewan Highways and Transportation (Highways); (2) two publications prepared annually by Highways; "Travel on Saskatchewan Highways" which provides a detailed statistical summary of the amount and characteristics of highway travel in Saskatchewan and, "Traffic Accident Facts" which provides a statistical summary of all traffic accidents in Saskatchewan; (3) Saskatchewan Government Insurance Records related to the total number and type of vehicles registered in Saskatchewan; and (4) special traffic studies undertaken by Highways.

3) The development of fleet specific profiles of accident experience for 5 large truck fleets operating throughout

Western Canada. These profiles were developed using data obtained from the files of the individual trucking companies. This information outlines the details of each accident that vehicles from these fleets had been involved in over a 4 year period.

4) A comparative analysis in which the accident experience of large trucks as detailed in the literature was compared with the accident experience of large trucks in Saskatchewan as determined from the TAIS data base and the fleet specific data. This comparative analysis provided insight into the safety experience of large trucks operating in Saskatchewan relative to the experience of large trucks operating in other jurisdictions. The accident experience of large trucks operating in Saskatchewan was also compared to the accident experience of other vehicles operating in Saskatchewan.

## 1.4 Layout of the Report

Chapter 2 presents an overview of the available literature related to the safety experience of large trucks and all vehicles operating in Saskatchewan. Chapter 3 presents a profile of accident experience of large trucks operating in Saskatchewan.

Chapter 4 presents the profiles of accident experience for 5 large fleets operating throughout Western Canada. Chapter 5 presents the results of a detailed statistical analysis, and Chapter 6 summarizes the findings and presents the conclusions.

## Chapter 2: Literature Review

### 2.1 Introduction

There have been numerous studies over the past 20 years on the safety experience of large trucks. Particular attention has been focused on the relative safety experience of single versus multiple trailer units. A comprehensive review of this literature has recently been completed. [1] Little purpose is served by repeating this review here. Instead, this Chapter provides only an overview.

Comparisons of accident experience of various types of vehicles are at best difficult and in many cases impossible. This results from the fact that the intrinsic safety of any vehicle is a function of many variables in addition to the type of vehicle involved. In comparing the safety of one vehicle type to another, the effects attributable to the mechanical differences between the two vehicles must be isolated from the large and confounding effects of road and environmental condition and driver experience and skill. In over-the-road situations, this is very difficult to accomplish.

Three general approaches have been used to establish the relative safety of various types of large trucks. These include:

1) Truck Handling and Stability Studies

In this type of study, both track testing and vehicle simulations have been used to compare the handling and stability properties of various vehicle types. Because of the controlled nature of these experiments, they are useful for in-depth examination of vehicle characteristics that may contribute to traffic accidents, but results cannot be easily translated into comparative over-the-road accident levels or accident rates. This type of analysis can sometimes be used effectively to explain or interpret specific accidents, but may not be much help for interpretation of findings of statistical accident analysis.

2) Traffic Operations Studies

This type of study measures the interactions between vehicles in the traffic stream such as vehicle distance and time headways, closure rates, speed differentials, conflicts, queuing, and passing behaviour. As with truck performance evaluations, the results can only suggest possible accident scenarios.

3) Accident Analysis

There are two general ways to undertake the analysis of accidents. In depth analysis of specific accidents provides insight into accident causation mechanisms. The second type uses aggregated accident and exposure data to estimate accident rates for different types of vehicles in over-the-road operation. There are, as will be noted below, numerous ways to express accident rates. Probably the most meaningful is in terms of accidents per unit of distance travelled. The advantage of this type of analysis is that it attempts to measure directly, under operating conditions, the question of primary interest -- namely, how safe is one vehicle type relative to another? The major disadvantage is that it is usually difficult or impossible to isolate the effects of vehicle type from the variety of confounding effects related to driver, road and environment using available data.

The methodology used here is that which analyzes historic accident and exposure data.

In attempting to compare safety experience, the difficulties of isolating the effects of vehicle type as a contributing factor to accidents are further compounded by the fact that researchers

have chosen (or out of necessity because of data constraints used) different measures to describe safety experience. These differences include the following:

(1) Differences in Measure of Effectiveness

In order for comparisons of safety experience to be meaningful, it is necessary to have a common measure for safety. Unfortunately there is no single measure that appropriately describes vehicle safety in its entirety. As a result, researchers have used numerous different measures in an attempt to describe the safety experience of highway traffic.

To illustrate, some researchers have chosen to describe safety experience by the total number of vehicles involved in accidents, while others have chosen to use the total number of vehicle accidents. These two measures are both appropriate macro measures of safety, but they are different and therefore cannot be compared directly.

(2) Differences in the Definition of an Accident

Various researchers have used different definitions for an accident. Some studies have considered only injury or fatal accidents; others have included property damage accidents in addition to injuries and fatalities. In the case of property

damage accident cases, there are often differences in the minimum value of a property damage accident for those included in the analysis, and this can change as a function of inflation and reporting rates. This can be very important when calculating accident rates because most accidents are, in fact, minor property damage accidents. To illustrate, the accident rate for one carrier considered in this project decreased by a factor of two when the definition of an accident was changed from one involving fatalities, injury or property damage exceeding $2000 to that involving fatalities, injury or property damage exceeding $5000. Further, it was found that 30-40% of all accidents for two of the carriers studied involved damages of less than $500.

The problem of definitions is further illustrated by the fact that some researchers, when considering serious accidents (i.e. injury or fatal accidents), use the number of accidents as the measurement criterion, while others use the number of injured persons or the number of fatalities as the criterion. These different definitions lead to substantially different results.

To illustrate, suppose there were ten accidents in a year which involved fatalities, five of which involved one fatality each, three which involved two fatalities, and two that involved four fatalities. If the total travel involved were 10 million vehicle km, then if accidents involving fatalities is the criterion, the rate is $10/10 \times 10^6$ or 1 fatal accident per million vehicle km.

On the other hand, if number of fatalities is the criterion, then the rate is (5 x 1) + (3 x 2) + (2 x 4) = $18/10 \times 10^6$ or 1.8 fatalities per million vehicle km. While the above is a hypothetical example, it is not unrealistic and illustrates that a subtle but important difference in definition could change the resulting measure by a factor of nearly two.

(3) Missing Data

Many of the existing studies have relied on databases created from accident report systems as a source of basic data. Researchers have identified varying degrees of nonreporting, incomplete or erroneous data files as potential problems in calculating accident rates. It is not uncommon to have 30% of the data files in these databases incomplete and thereby not included in the analysis. Nonreporting is a particular problem with low value property damage accidents and there is no sure way to know the extent of this phenomena. Data available in this project indicated that 20% of accidents, in particular property damage accidents with damage less than $3000 go unreported to police.

(4) Different Vehicle Classification Systems

Difficulties also arise from the use of different vehicle classification systems. Some accident rates are calculated for

trucks where "trucks" are all vehicles over 5000 kg in registered gross vehicle weight (GVW). On the other hand, accident rates may be calculated separately for straight trucks exceeding 5000 kg GVW and articulated trucks.

### (5) Difficulties in Determining Exposure

Researchers have recognized the need to include a measure of exposure in the analysis of safety experience. This is most often done by calculating the number of accidents per unit distance travelled (i.e. an accident rate). Total distance travelled by vehicle classes usually must be estimated. This presents a particular challenge because the calculations are constrained by the availability and quality of information. Invariably the calculations of accident rates, using database information, rely on vehicle counts and vehicle classification surveys. These are most often periodic short interval counts taken at a particular location, and therefore can have considerable uncertainty inherent in them. This is illustrated by means of a sensitivity analysis described later in this report.

Other studies have tried to overcome the limitations in the database approach by using detailed fleet specific data. But this micro approach is also hampered by the lack of sufficiently detailed exposure data, even at the fleet level. To illustrate,

suppose a researcher were interested in the relative safety experience of double trailer units that used two different mechanisms to connect the trailers. The obvious approach would be to determine accident rates (maybe by severity) for the two configurations. While fleet operators may have the accident data in sufficient detail, it is unlikely they would have the exposure data in sufficient detail. This then either precludes such comparisons or requires specifically designed and implemented studies at considerable cost.

(6) Small Samples

Contrary to many prevailing opinions, large trucks are involved in a relatively small number of accidents. This is particularly true for serious accidents involving injuries and/or fatalities. The result is that there is a high variability in reported research findings. It is often difficult or impossible to comment intelligently about the statistical significance of observed variations. If such results were reported, they can often be misused.

## 2.2 Results of Other Studies

The above difficulties are cited to caution the reader not to expect too much from the literature as well as to indicate that it is easy to misinterpret the available data.

On first inspection, the relative safety experience for various vehicle types as reported in the literature appears to be highly variable and often conflicting. For example, the reported accident rates for doubles ranges from about one-half that of single trailer units to more than six times as much. Commentators can therefore be selective in the study quoted to justify their point of view.

This variability in reported results is attributable in most cases to differences in underlying data, analysis methods, definitions, and control (or lack thereof) of factors other than vehicle type that could affect the relative accident experience observed. That is, most of the differences are attributable to effects other than differences in vehicle type (i.e. definitions, road type, environmental conditions, etc.).

A detailed review [1] indicated that of 14 available studies reporting accident rates for double and single trailer units:

> "Five stood out as studies that were most nearly free from obvious methodological flaws and that made reasonable attempts to minimize the confounding effects of the operating environment, and that reflect accident experience under conditions that are typical of roads in the nation (in the U.S.A.)".

Even these five studies (summarized on Table 2.1) were noted to:

TABLE 2.1
SUMMARY OF COMPARATIVE ACCIDENT RATE STUDIES (1)

| Study | Vehicles and Roads Represented | Years of Data | Involvement-Rate Ratio: Twins to Tractor-Semitrailers | | |
|---|---|---|---|---|---|
| | | | Fatal Accidents | Casualty Accidents | Total Accident |
| Chirachavala and O'Day [2] (2) | Nationwide, intercity van trailers, ICC-authorized carriers | 1977 | - | - | 0.98 (3) |
| Glennon [3] | Consolidated Freightways, nationwide | 1976 - 1980 | - | - | 1.06 (3) |
| Yoo, Reiss, and McGee [4] | Rural roads, California | 1974 | 1.05 | 0.94 | - |
| BMCS [5] (4) | Interstate carriers, nationwide | 1969 - 1980 | 1.20 | 1.08 | - |
| Graf and Archuleta [6] (5) | Rural roads, California | 1979 - 1983 | 0.93 | 1.03 | 1.12 |
| | Urban roads, California | 1979 - 1983 | 2.29 | 0.82 | 0.79 |

(1) Source: Table 4.2 Page 130 - Twin Trailer Trucks, Special Report 211, Transportation Research Board, National Research Council 1986

(2) For details of references, see list of references at the end of the report.

(3) Ratio reported not to be statistically significantly different from 1. Significance tests were not reported in the other studies shown, but the uncertainties in all studies probably are dominated by possible systematic biases rather than random error.

(4) Ratio of average number of deaths or casualties per mile travelled for 10 carrier periods. See Appendix F, Special Report 211, TRB

(5) Data from multiple sites have been combined to compute the rates shown with weights equal to total (semitrailer plus multitrailer) mileage at each site. See Appendix F, Special Report 211, TRB.

REFERENCES FROM TABLE 2.1


1. T. Chirachavala and O'Day, A Comparison of Accident Characteristics and Rates for Combination Vehicles with One or Two Trailers, Highway Safety Research Institute, University of Michigan, Ann Arbor, Aug. 1981

2. J.C. Glennon, "Matched Pair Analysis", Consolidated Freightways Corporation v. Larson et al., 81-1230, U.S. District Court, Middle District of Pennsylvania, Aug. 12, 1981

3. C.S. Yoo, M.L. Reiss, and H.W. McGee, Comparison of California Accident Rates for Single and Double Tractor-Trailer Combination Trucks, Report FHWA-RD-78-94. BioTechnology, Inc., Falls Church, VA., March 1978

4. Safety Comparisons of Doubles versus Tractor-Semitrailer Operation, Bureau of Motor Carrier Safety, FHWA, U.S. Department of Transportation, June 1983

5. V.S. Graf and K. Archuleta, Truck Accidents by Classification, California Department of Transportation, Sacramento, California, Feb. 1985

> "have shortcomings related to uncertainties related to accuracy of underlying data, to the representativeness of the roads where the travel and accidents occurred, or to the possibility that environmental factors not accounted for in the study design or analysis could explain part of the apparent differences between accident rates."

The discussion thus far has focused on relative accident experience of double and single trailer units. Nothing has been said about the absolute values for accident rates of large trucks or the absolute or relative values of accident rates of large trucks compared to cars.

There are difficulties in using absolute values for accident rates. In order for relative rates to be meaningful, common definitions and common operating environments are only required between the doubles and singles within any given study. If absolute values are compared, there is a requirement for common definitions and other factors between the studies being compared. Since this inter-study commonality rarely exists, comparisons of absolute values between studies are not usually meaningful.

For similar reasons, comparisons between absolute accident rates for large trucks and other vehicles (i.e. cars) are rarely presented, and when they are, they may not be particularly informative.

With this caution thus noted, Table 2.2 summarizes some accident rates as reported for large trucks and other vehicles. The

numbers of most interest in the context of this study are the accident rates for all vehicles operated on Saskatchewan provincial highways. The overall accident rate for vehicles operating on provincial highways in 1986 was 0.81. The rates for injury accidents and fatal accidents were 0.17 and 0.017 accidents per million vehicle km respectively.

## 2.3 Summary

The available literature seems to suggest that the accident experience of double and single trailer units when operated under similar conditions is similar. It is difficult to compare absolute values of accident rates for different vehicles operating in different circumstances because of the problems associated with confounding effects. Having noted this difficulty, though, the available statistics suggest that accident rates (for all vehicles) including all fatal, injury and property damage accidents exceeding $200 for Saskatchewan provincial highways is in the order of 0.81 accidents per million vehicle km. The injury accident and fatal accident rates for provincial highways are in the order of 0.17 and 0.017 accidents per million vehicle km respectively.

TABLE 2.2

ACCIDENT RATES BY VEHICLE TYPE

| | Large Trucks | | Other Vehicles |
|---|---|---|---|
| | Single Trailer | Multiple Trailer | |
| FHWA (1) | | | |
| Road Class | | | |
| Rural Interstate | .152 | .064 | .240 (2) |
| Other Rural | .258 | .135 | .451 |
| Urban Interstate | .353 | .216 | .484 |
| Other Urban | .476 | .253 | 1.000 |
| Saskatchewan Highways and Transportation | | | |
| Popoff [7] (2) | 1.37 | 1.12 | 1.41 |
| Saskatchewan '86 all vehicles, all accidents, all roads | | | 3.17 (3) |
| all vehicles, all accidents, prov. highways | | | .81 (4) |
| all vehicles, injury accidents, prov. highways | | | .17 (5) |
| all vehicles, fatal accidents, prov. highways | | | .017 (6) |
| Chirachavala and O'Day (7) | .765 | .761 | |

NOTES TO TABLE 2.2

1) Involvement rates for single trailer and multi-trailer combination trucks and other vehicles from FHWA Accident Rate Monitoring. Source: Table 4.5, page 143, Twin Trailer Trucks Special Report 211, Transportation Research Board 1986. Unpublished 1983-86 accident and travel data from the federally designated network reported by seven states to FHWA. Seven states (Illinois, Missouri, Nevada, Utah, Washington, West Virginia, and Wisconsin) involvements in fatal and injury accidents per million vehicle km.

2) Popoff, A.J. Heavy Truck Involvement in Traffic Accidents, Saskatchewan Highways and Transportation, November 1982. 1980 vehicle involvement rates in accidents on Saskatchewan provincial highways expressed as accidents per million vehicle km. Accidents include all injuries, fatalities, and property damage greater than $200.

3) Accidents per million vehicle km. Includes all injury, fatal, and property damage accidents exceeding $200 for all vehicle types on all roads in Saskatchewan (i.e. rural provincial highways, rural roads and urban streets).

4) Accidents per million vehicle km. Includes all injury, fatal and property damage accidents exceeding $200 for all vehicle types on provincial highways in Saskatchewan.

5) Injury accidents per million vehicle km. Includes all injury accidents for all vehicle types on provincial highways in Saskatchewan.

6) Fatal accidents per million vehicle km. Includes all fatal accidents for all vehicle types on provincial highways in Saskatchewan.

7) An accident was defined as any incident involving a fatality, injury or property damage exceeding $2000.

## Chapter 3: Profile of Accident Experience in Saskatchewan

### 3.1 Introduction

The first section of this Chapter provides a statistical profile of vehicle accidents in Saskatchewan. This is followed by a profile of accident experience of large trucks in Saskatchewan and a discussion of exposure as an appropriate parameter in determining relative accident experiences. Also included is the results of a sensitivity analysis related to the calculation of exposure. This provides some insight into the level of uncertainty inherent in accident rate calculations.

### 3.2 Profile of Vehicle Accidents in Saskatchewan

Table 3.1 and Figure 3.1 show the total number of reported accidents in Saskatchewan for each year from 1980 to 1986. Table 3.2 and Figure 3.2 show the total number of vehicles involved in accidents in Saskatchewan by year. These statistics include all reported accidents by all vehicle types.

Private property accidents were excluded beginning in 1981 and the definition of a reportable accident changed between 1983 and 1984 from an accident involving a fatality, injury or exceeding $200 in damages to one involving a fatality, injury or exceeding $500 in damages. These changes in definition account for the

TABLE 3.1
TOTAL NUMBER OF REPORTED ACCIDENTS
IN SASKATCHEWAN

| YEAR | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 |
|---|---|---|---|---|---|---|---|
| NUMBER OF ACCIDENTS | 48,274 | 38,285 | 40,366 | 39,855 | 32,646 | 32,699 | 33,374 |

SOURCE: Saskatchewan Highways and Transportation

(1) Beginning in 1981, private property accidents were no longer included in TAIS. These accounted for 17.5% of all reported accidents in 1980.
(2) Reporting threshold changed from $200.00 to $500.00 in January 1984.

TABLE 3.2
TOTAL NUMBER OF VEHICLES INVOLVED IN ACCIDENTS
IN SASKATCHEWAN

| YEAR | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 |
|---|---|---|---|---|---|---|---|
| NUMBER OF ACCIDENTS | 81,634 | 63,930 | 68,872 | 68,582 | 56,037 | 56,131 | 57,426 |

SOURCE: Saskatchewan Highways and Transportation

See notes to Table 3.1

FIGURE 3.1
TOTAL NUMBER OF REPORTED ACCIDENTS
IN SASKATCHEWAN

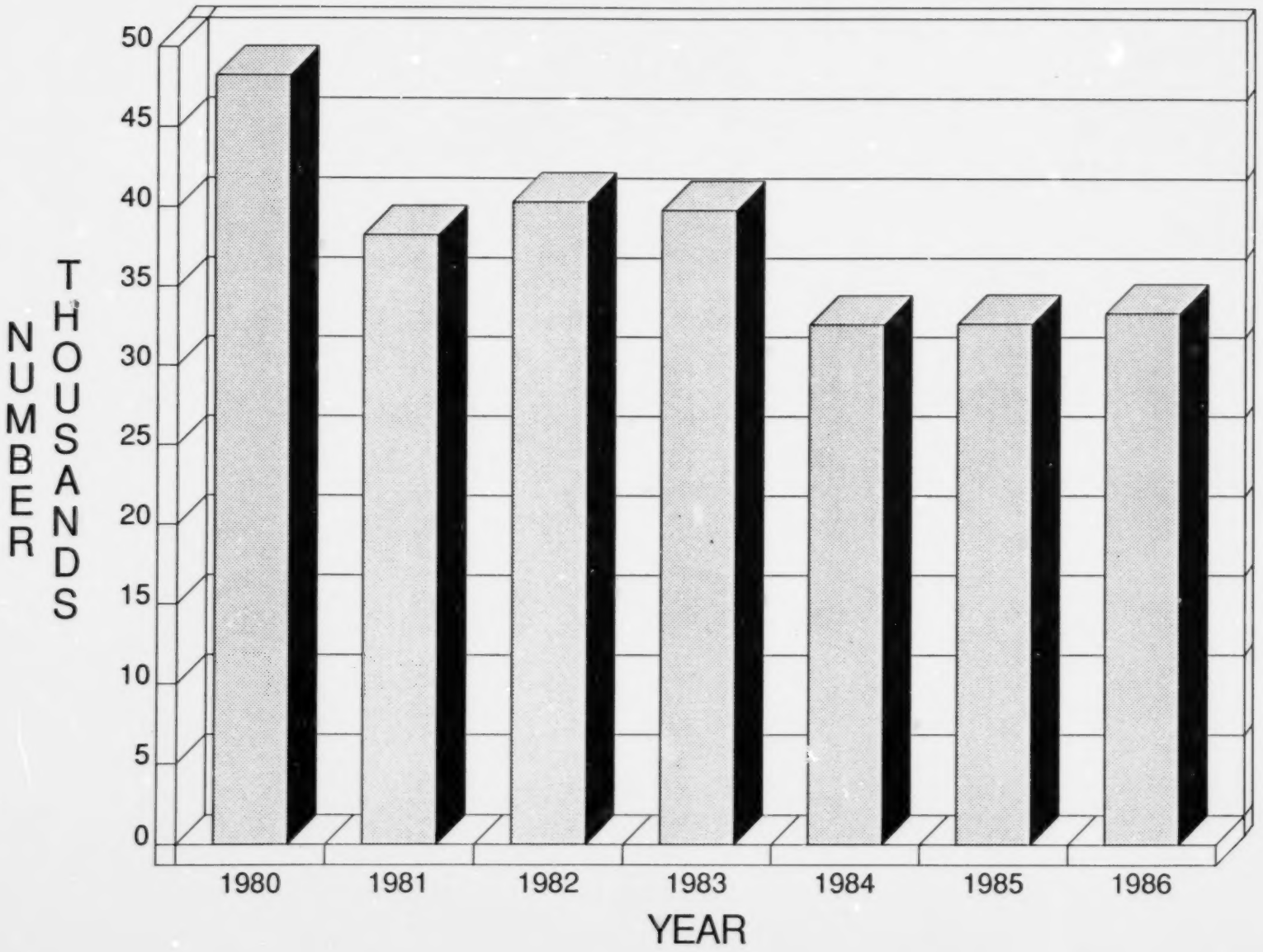
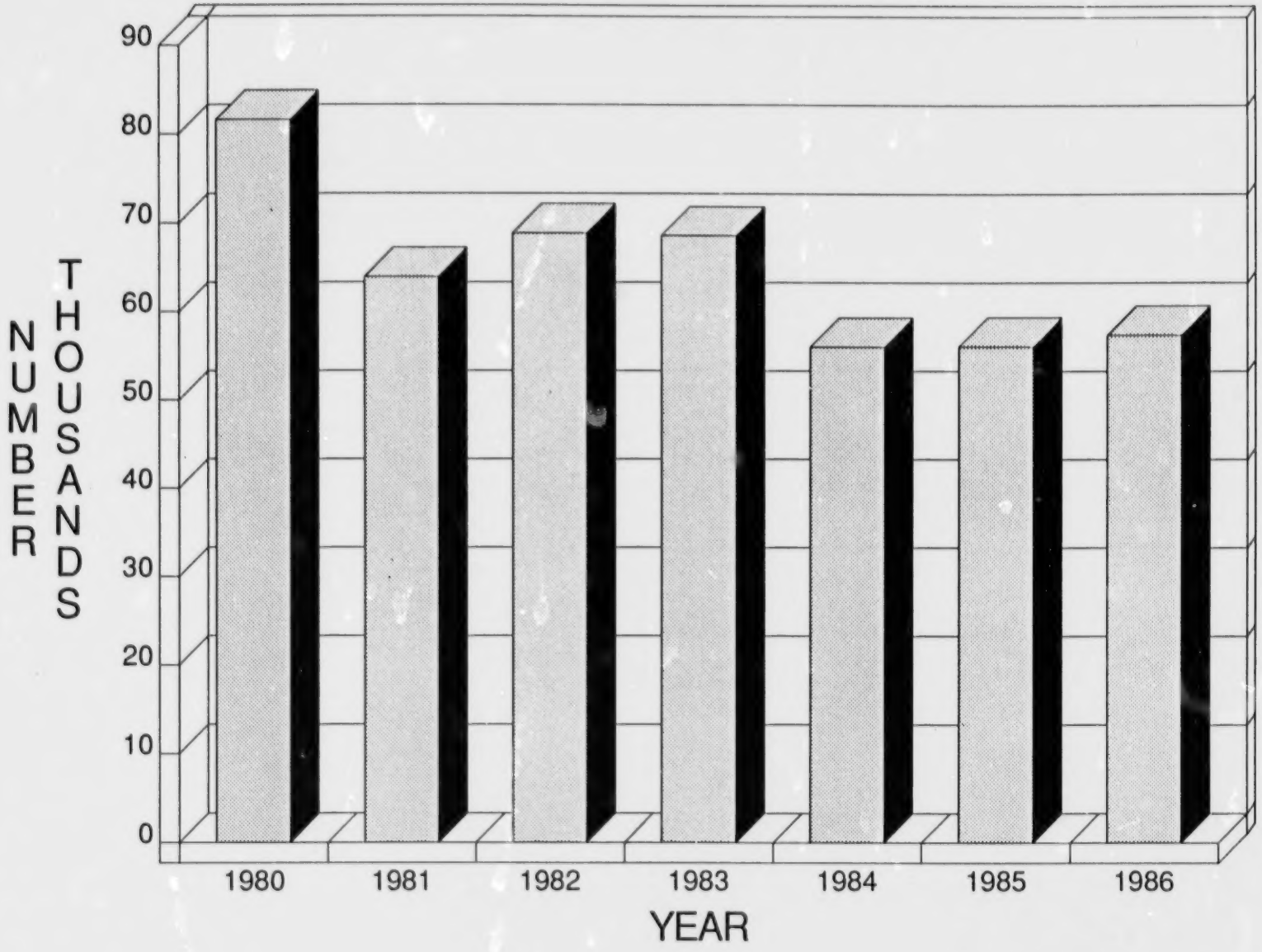


FIGURE 3.2
TOTAL NUMBER OF VEHICLES INVOLVED
IN ACCIDENTS IN SASKATCHEWAN



substantial decrease in the number of reported accidents between 1980 and 1981 and in the 1984 to 1986 period relative to 1983 and prior.

From these figures, it can be seen that there are approximately 33,000 reported accidents annually in Saskatchewan, involving about 57,000 vehicles.

Table 3.3 and Figure 3.3 show the total number of vehicles involved in reported accidents by the five major categories (cars, half tons, others, straight trucks and articulated trucks). Figure 3.4 illustrates in a pie chart the total number of vehicles involved in reported accidents in Saskatchewan by major vehicle type in 1986. It can be noted that articulated trucks accounted for approximately 2% of the total number of vehicles involved in reported accidents, straight trucks 2%, 1/2 tons 22%, cars 64% and others 10%.

Table 3.4 and Figure 3.5 show the total number of vehicles involved in reported accidents by vehicle type by severity for each year 1983 to 1986. Table 3.5 and Figure 3.6 summarize this information.

From this information, it can be seen that 0.3% to 0.4% of all accidents involving cars involved fatalities, 13% to 17% involved personal injuries and 82% to 87% involved only property damage.

TABLE 3.3
TOTAL NUMBER OF VEHICLES INVOLVED IN REPORTED ACCIDENTS
IN SASKATCHEWAN BY VEHICLE TYPE

| TYPE VEHICLE | YEAR | | | |
|---|---|---|---|---|
| | 1983 | 1984 | 1985 | 1986 |
| CARS | 44249 | 36041 | 35863 | 37357 |
| 1/2 TONS | 15365 | 12800 | 13002 | 12966 |
| OTHERS | 6869 | 5389 | 5300 | 6083 |
| STRAIGHT TRUCKS | 1144 | 945 | 993 | 890 |
| ARTICULATED TRUCKS | 955 | 862 | 973 | 930 |
| TOTAL | 68582 | 56037 | 56131 | 58226 |

FIGURE 3.3
TOTAL NUMBER OF VEHICLES INVOLVED IN REPORTED
ACCIDENTS IN SASK. BY VEHICLE TYPE

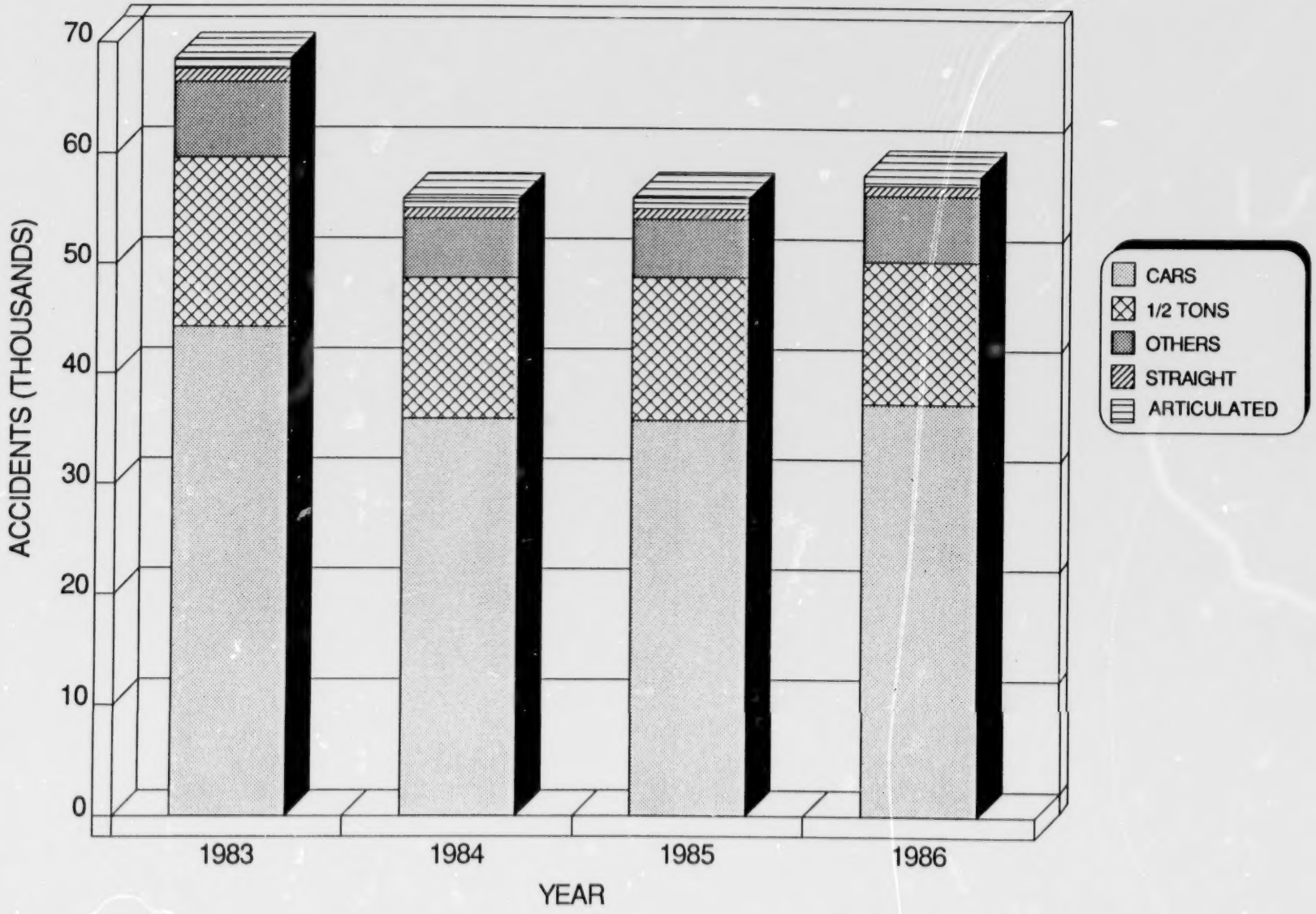


FIGURE 3.4

TOTAL NUMBER OF VEHICLES INVOLVED IN REPORTED ACCIDENTS
IN SASK. BY VEHICLE TYPE (1986)

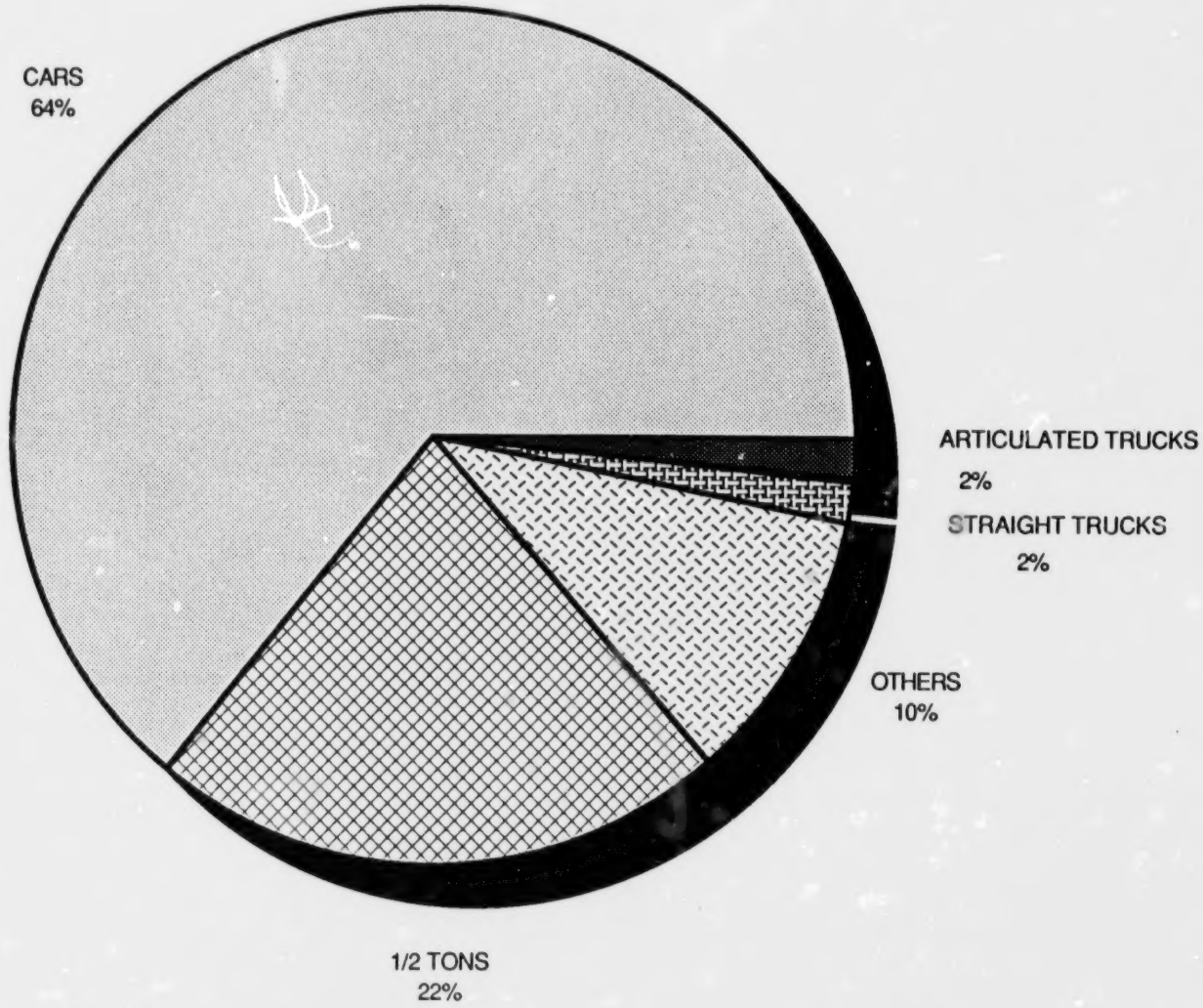


TABLE 3.4
TOTAL NUMBER OF VEHICLES INVOLVED IN REPORTED ACCIDENTS
BY VEHICLE TYPE BY SEVERITY

| YEAR | | NUMBER OF ACCIDENTS | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | VEHICLE TYPE | PROPERTY DAMAGE | % | PERSONAL INJURY | % | FATALITY | % | TOTAL |
| 1983 | CAR | 38363 | 86.70 | 5754 | 13.00 | 132 | 0.30 | 44249 |
| | 1/2 TON | 13312 | 86.64 | 1973 | 12.84 | 80 | 0.52 | 15365 |
| | OTHERS | 5674 | 82.60 | 1162 | 16.92 | 33 | 0.48 | 6869 |
| | STRAIGHT | 988 | 86.36 | 141 | 12.33 | 15 | 1.31 | 1144 |
| | ARTICULATED | 782 | 81.88 | 157 | 16.44 | 16 | 1.68 | 955 |
| | TOTAL | 59119 | | 9187 | | 276 | | 68582 |
| 1984 | CAR | 30222 | 83.85 | 5684 | 15.77 | 135 | 0.37 | 36041 |
| | 1/2 TON | 10863 | 84.87 | 1856 | 14.50 | 81 | 0.63 | 12800 |
| | OTHERS | 4332 | 80.39 | 1041 | 19.32 | 16 | 0.30 | 5389 |
| | STRAIGHT | 807 | 85.40 | 128 | 13.54 | 10 | 1.06 | 945 |
| | ARTICULATED | 685 | 79.47 | 153 | 17.75 | 24 | 2.78 | 862 |
| | TOTAL | 46909 | | 8862 | | 266 | | 56037 |
| 1985 | CAR | 29744 | 82.94 | 5984 | 16.69 | 135 | 0.38 | 35863 |
| | 1/2 TON | 10854 | 83.48 | 2071 | 15.93 | 77 | 0.59 | 13002 |
| | OTHERS | 4094 | 77.25 | 1170 | 22.08 | 36 | 0.68 | 5300 |
| | STRAIGHT | 833 | 83.89 | 150 | 15.11 | 10 | 1.01 | 993 |
| | ARTICULATED | 773 | 79.45 | 180 | 18.50 | 20 | 2.06 | 973 |
| | TOTAL | 46298 | | 9555 | | 278 | | 56131 |
| 1986 | CAR | 30707 | 82.20 | 6501 | 17.40 | 149 | 0.40 | 37357 |
| | 1/2 TON | 10840 | 83.60 | 2031 | 15.66 | 95 | 0.73 | 12966 |
| | OTHERS | 4889 | 80.37 | 1156 | 19.00 | 38 | 0.62 | 6083 |
| | STRAIGHT | 728 | 81.80 | 153 | 17.19 | 9 | 1.01 | 890 |
| | ARTICULATED | 746 | 80.22 | 164 | 17.63 | 20 | 2.15 | 930 |
| | TOTAL | 47910 | | 10005 | | 311 | | 58226 |

SOURCE: TRAFFIC ACCIDENT FACTS
Saskatchewan Highways and Transportation

FIGURE 3.5
TOTAL NUMBER OF VEHICLES INVOLVED IN REPORTED ACCIDENTS IN SASK. BY VEHICLE TYPE AND SEVERITY

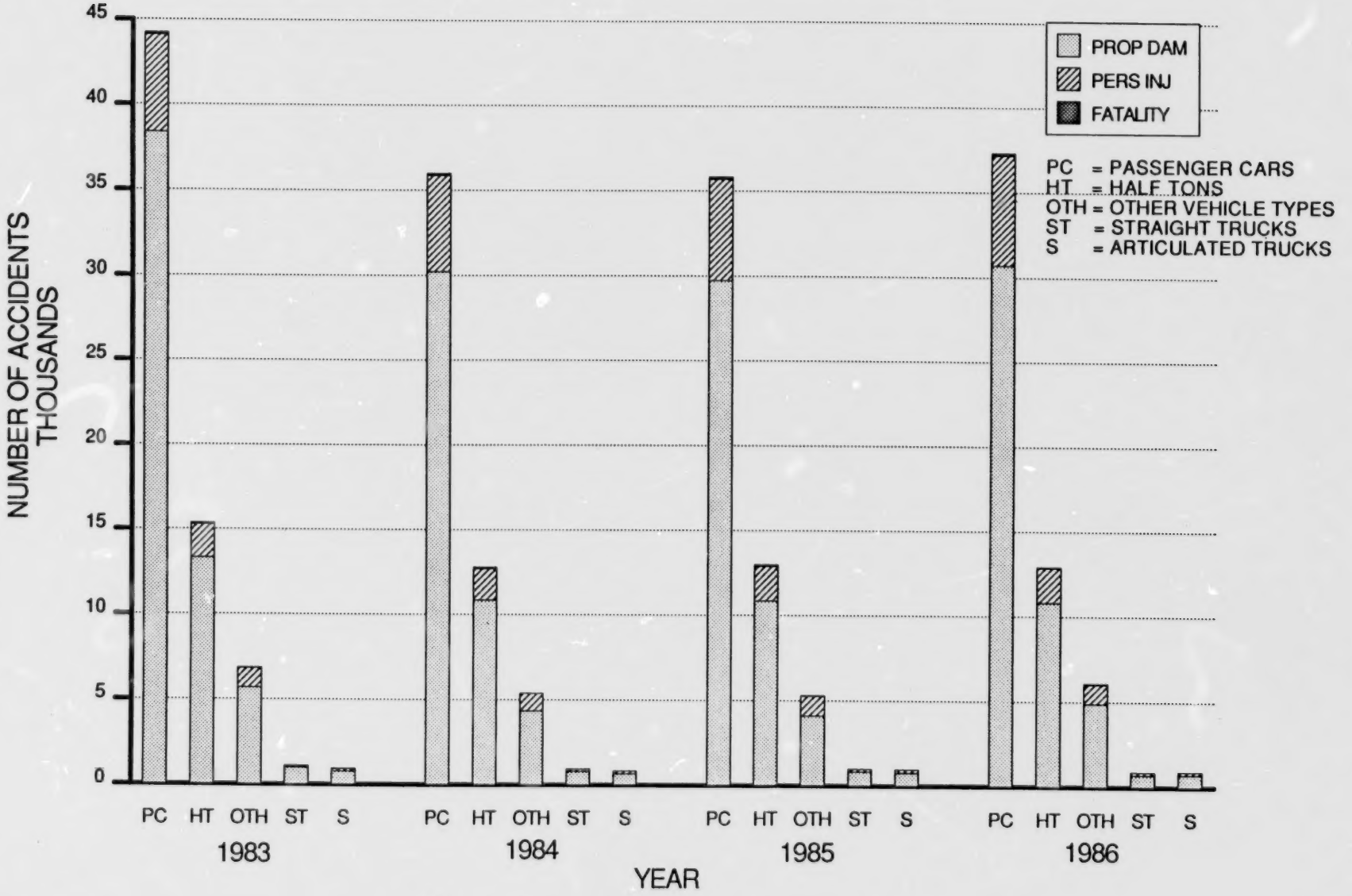
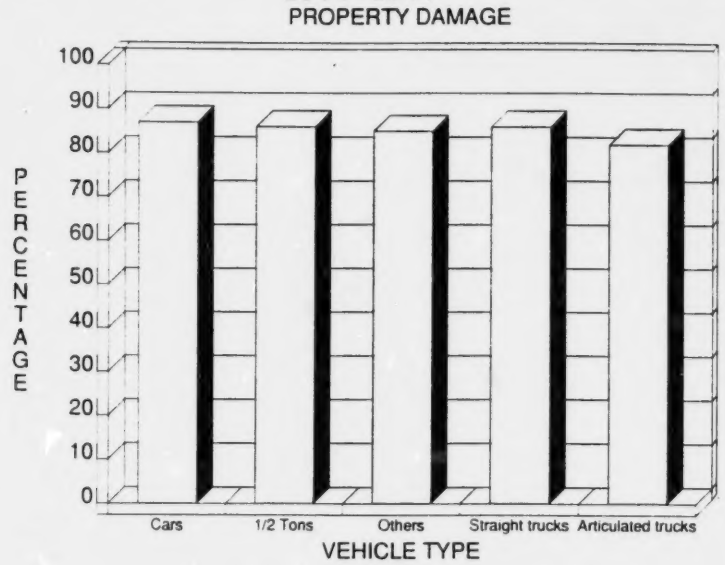
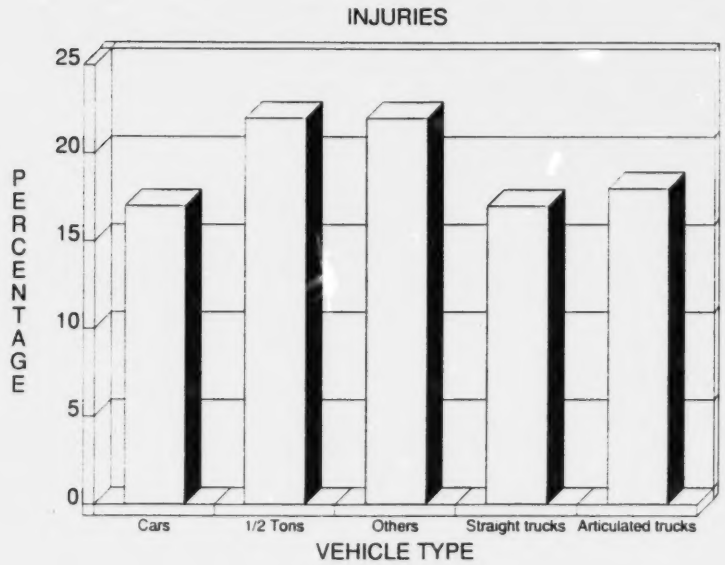


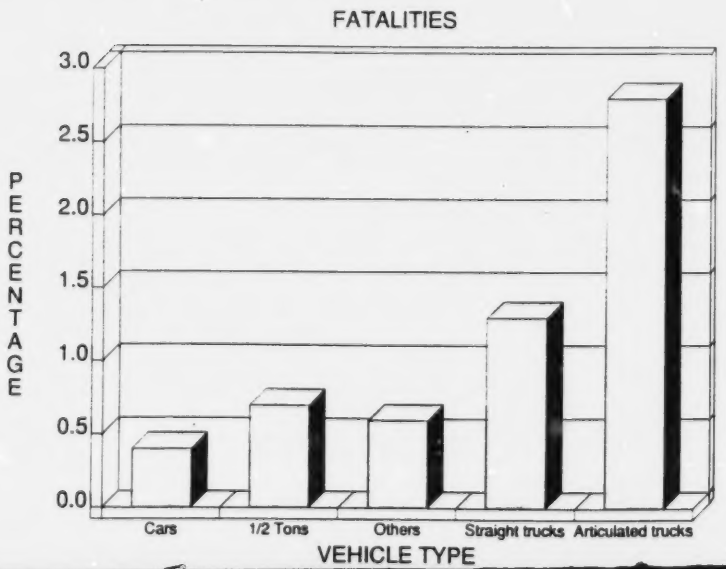
TABLE 3.5
SUMMARY OF PERCENT VEHICLES INVOLVED IN REPORTED ACCIDENTS
IN SASKATCHEWAN BY VEHICLE TYPE BY SEVERITY
1983-1986

| VEHICLE TYPE | % PROPERTY DAMAGE | % INJURIES | % FATALITIES |
|---|---|---|---|
| CARS | 82-87% | 13-17% | .3-.4% |
| 1/2 TONS | 83-86% | 12-22% | .5-.7% |
| OTHERS | 77-85% | 16-22% | .3- 6% |
| STRAIGHT TRUCKS | 81-86% | 12-17% | 1-1.3% |
| ARTICULATED TRUCK | 79-82% | 16-18% | 1.7-2.8% |

FIGURE 3.6
SUMMARY OF PERCENT TOTAL VEHICLES INVOLVED IN REPORTED ACCIDENTS IN SASKATCHEWAN BY VEHICLE TYPE BY SEVERITY
1983-1986



For 1/2 tons, 0.55 to 0.7% involved fatalities, 12% to 16% injuries and 83% to 86% only property damage. For other vehicle types, 0.3 to 0.6% involved fatalities, 16% to 22% injuries, and 77% to 85% property damage. For straight trucks, 1% to 1.3% involved fatalities, 12% to 17% injuries and 81% to 86% property damage. For articulated trucks 1.7% to 2.8% involved fatalities, 16% to 18% injuries and 79% to 82% property damage.

These statistics suggest that a larger proportion of accidents involving straight trucks and articulated trucks result in fatalities relative to other vehicle types. This conclusion is similar to the findings reported by others.

## 3.3 Number of Articulated Truck Accidents

Table 3.6 and Figure 3.7 illustrate the total number of reported accidents involving articulated trucks by location and severity in Saskatchewan in 1985. As shown, 60% of all articulated truck accidents occurred in rural areas. Fifty-six percent of the property damage accidents, 71% of the injury accidents, and 89% of the fatal articulated truck accidents occurred in rural areas.

Clearly, the majority of serious articulated truck accidents (i.e. those involving injury and fatalities) occur in rural areas. This is likely attributable to the higher operating speeds in rural areas and therefore the more serious nature of

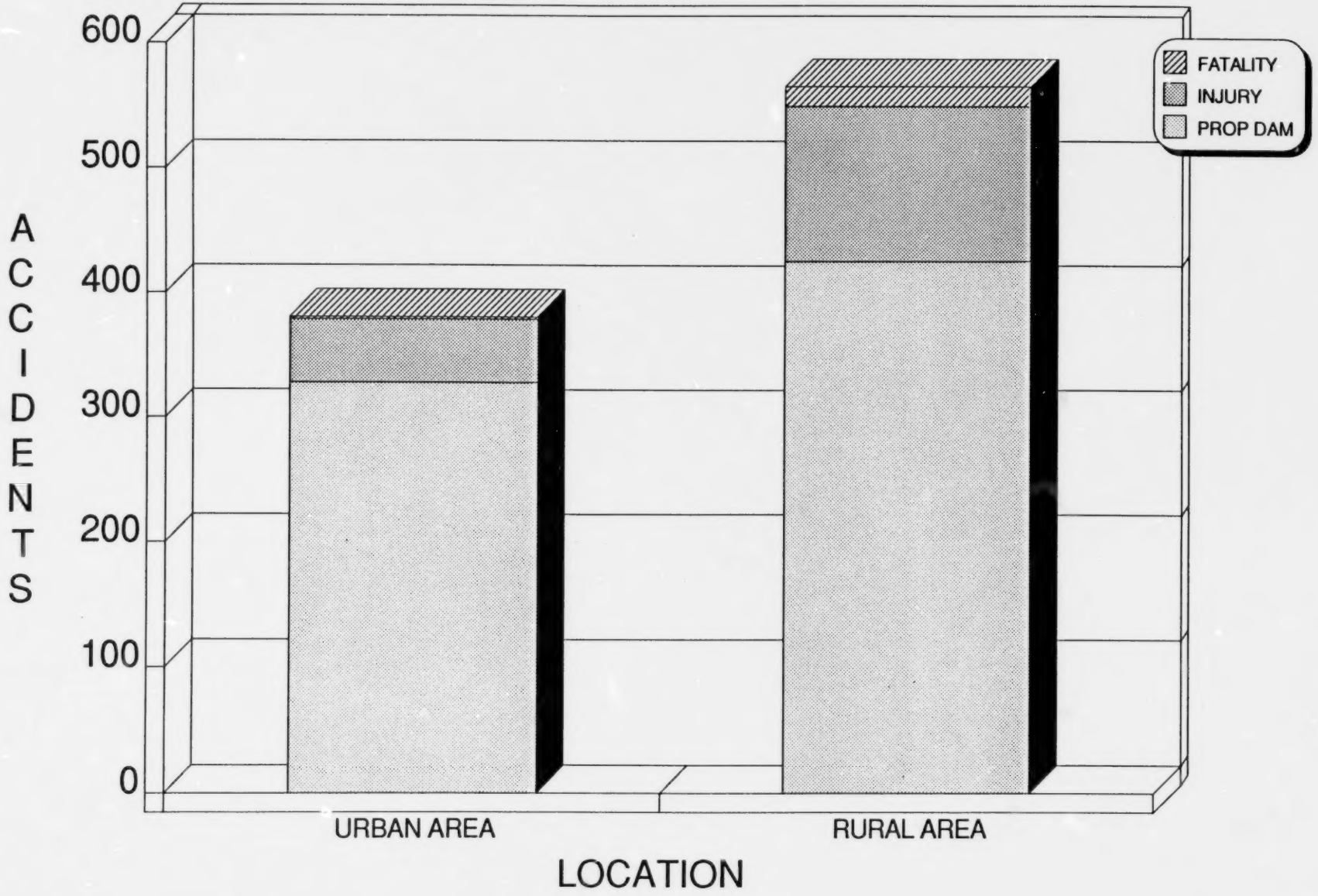
TABLE 3.6
TOTAL NUMBER OF REPORTED ARTICULATED TRUCK ACCIDENTS
BY SEVERITY AND LOCATION IN SASK IN 1985

| SEVERITY | LOCATION | | | | | |
|---|---|---|---|---|---|---|
| | URBAN AREA | | RURAL AREA (1) | | TOTAL | |
| | NUMBER OF ACCIDENTS | % | NUMBER OF ACCIDENTS | % | NUMBER OF ACCIDENTS | % |
| PROPERTY DAMAGE | 328 | 44 | 426 | 56 | 754 | 80 |
| INJURY | 51 | 29 | 124 | 71 | 175 | 18 |
| FATALITY | 2 | 11 | 16 | 89 | 18 | 2 |
| TOTAL | 381 | 40 | 566 | 60 | 947 | 100 |

SOURCE: Traffic Accident Information System,
Saskatchewan Highways and Transportation.

(1) Rural areas include both rural roads, provincial highways and other rural locations.

FIGURE 3.7
REPORTED ARTICULATED TRUCK ACCIDENTS
BY SEVERITY BY LOCATION IN SASK. (1985)



resulting accidents.

Table 3.7 and Figure 3.8 show the number of articulated truck accidents by total accident cost by contributing factor for 1985. It is noted that human condition (which includes driver inattention, driver distraction, had been drinking, driver inexperience, etc.), and environmental factors (which include animal action, slippery surface, loose gravel, obstructed view etc.) account for 32% and 40% of the total accidents respectively. Human condition and environmental factors are the major contributing factors in articulated truck accidents.

Table 3.8 and Figure 3.9 illustrate the number of registered vehicles by type in Saskatchewan. Table 3.9 and Figure 3.10 illustrate the number of vehicles involved in accidents by vehicle type by severity per 1000 registered vehicles in 1985. It is noted that 98.1 cars were involved in accidents per 1000 registered vehicles, 49.2 1/2 tons, 28.2 other vehicles, 99.7 straight trucks, and 162.8 articulated trucks. This illustrates that articulated trucks are over-represented in accidents relative to their proportion of the total fleet.

TABLE 3.7
NUMBER OF REPORTED ARTICULATED TRUCK ACCIDENTS
BY ACCIDENT COST AND CONTRIBUTING FACTOR
IN SASK. IN 1985

| ACCIDENT COST | NUMBER OF ACCIDENTS (1) | | | | |
|---|---|---|---|---|---|
| | HUMAN CONDITION | HUMAN ACTION | VEHICLE CONDTION | ENVIRONMENT | TOTAL |
| 0 TO $500 | 32 | 4 | 11 | 30 | 77 |
| $501 TO $1,000 | 42 | 7 | 23 | 49 | 121 |
| $1,001 TO $2,000 | 52 | 15 | 16 | 43 | 126 |
| $2,001 TO $5,000 | 29 | 13 | 15 | 52 | 109 |
| $5,001 TO $10,000 | 14 | 5 | 13 | 31 | 63 |
| $10,000 AND HIGHER | 27 | 24 | 24 | 34 | 109 |
| TOTAL | 196 | 68 | 102 | 239 | 605 |
| % OF TOTAL | 32.40 | 11.24 | 16.86 | 39.50 | 100 |

SOURCE: Traffic Accident Information System
Saskatchewan Highways and Transportation

(1) Includes all rural accidents ( Provincial highways,rural roads and other rural locations).

FIGURE 3.8
% OF ARTICULATED TRUCK ACCIDENTS
BY CONTRIBUTING FACTOR

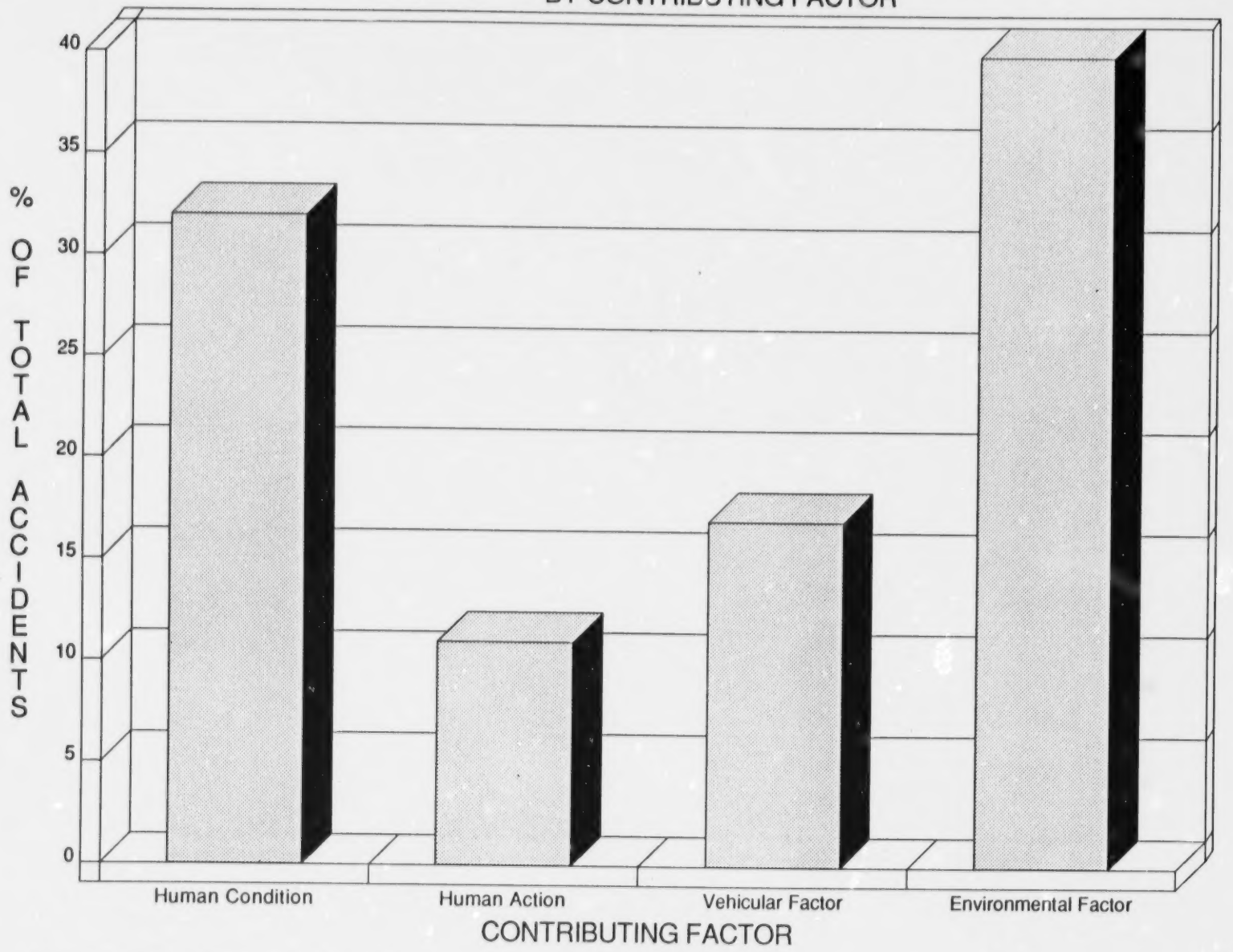


TABLE 3.8

NUMBER OF REGISTERED VEHICLES IN SASKATCHEWAN
BY VEHICLE TYPE

| YEAR | CARS | 1/2 TONS | OTHERS | STRAIGHT TRUCKS | ARTICULATED TRUCK | TOTAL |
|---|---|---|---|---|---|---|
| 1983 | 381978 | 264971 | 160640 | 8805 | 5938 | 822332 |
| 1984 | 376293 | 258710 | 173236 | 9472 | 4913 | 822624 |
| 1985 | 376841 | 257506 | 187896 | 10724 | 5213 | 838180 |
| 1986 | 385212 | 252842 | 198952 | 11566 | 5090 | 853662 |

PERCENT OF REGISTERED VEHICLES IN SASKATCHEWAN
BY VEHICLE TYPE

| YEAR | CARS | 1/2 TONS | OTHERS | STRAIGHT TRUCKS | ARTICULATED TRUCK | TOTAL |
|---|---|---|---|---|---|---|
| 1983 | 46.45% | 32.22% | 19.53% | 1.07% | 0.72% | 100.00% |
| 1984 | 45.74% | 31.45% | 21.06% | 1.15% | 0.60% | 100.00% |
| 1985 | 44.96% | 30.72% | 22.42% | 1.28% | 0.62% | 100.00% |
| 1986 | 45.12% | 29.62% | 23.31% | 1.35% | 0.60% | 100.00% |

SOURCE: Saskatchewan Government Insurance, Personal Communication.
Traffic Accident Facts, Saskatchewan Highways and Transportation

FIGURE 3.9
NUMBER OF REGISTERED VEHICLES IN SASK.
BY VEHICLE TYPE

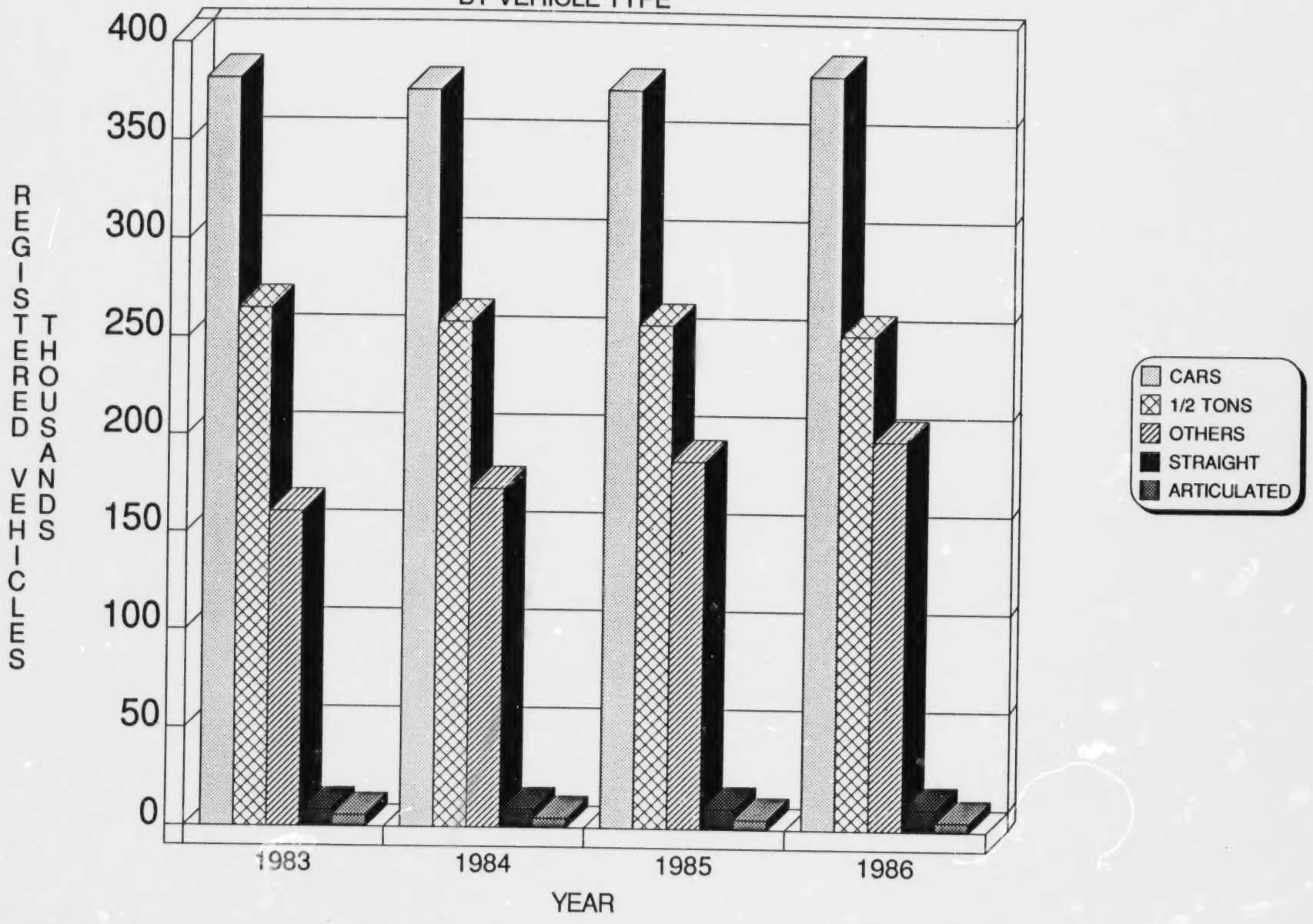
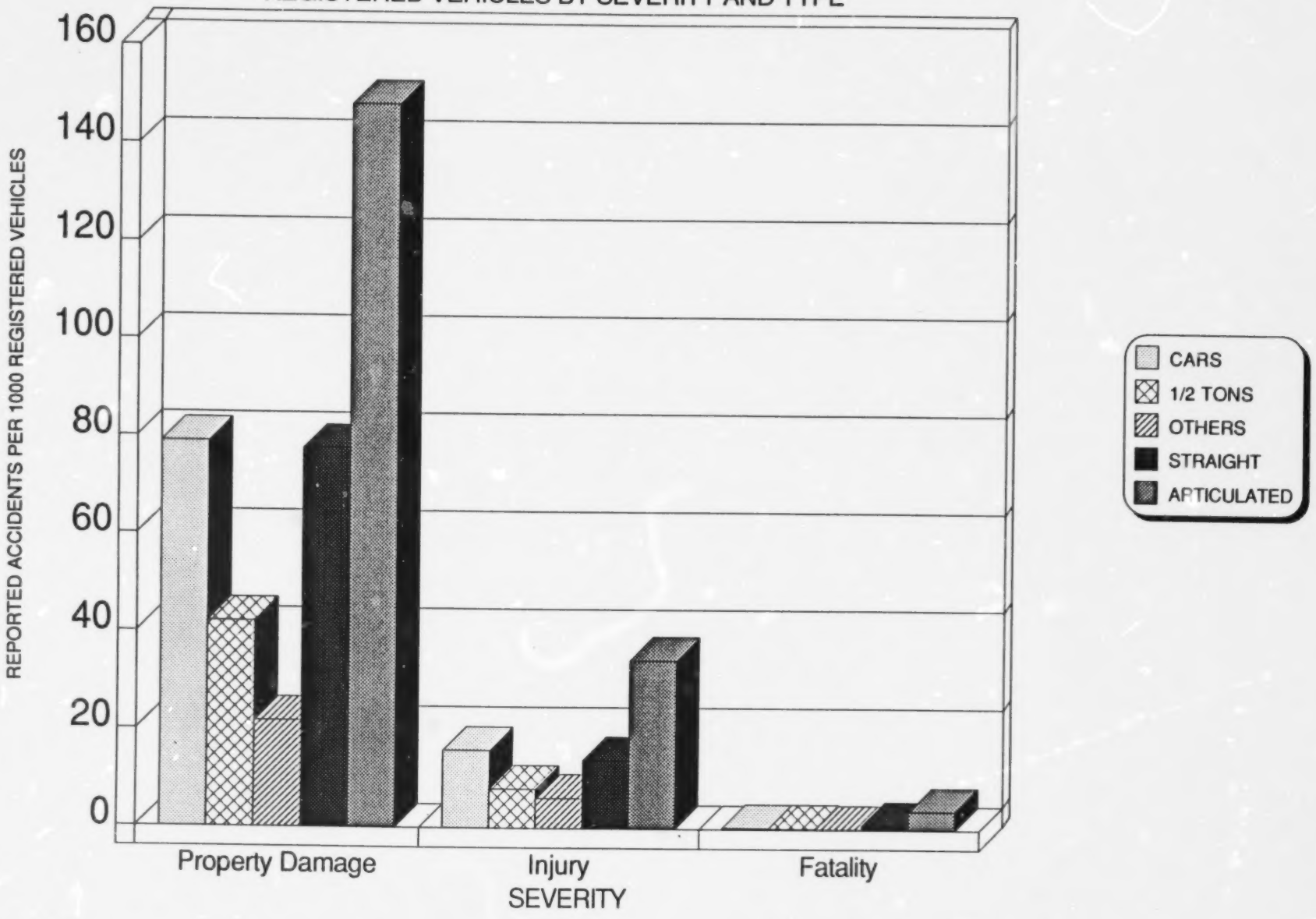


TABLE 3.9
NUMBER OF VEHICLES INVOLVED IN REPORTED ACCIDENTS PER 1000 REGISTERED VEHICLES IN SASKATCHEWAN IN 1985 (1)

| VEHICLE TYPE | PROPERTY DAMAGE | INJURY | FATALITY | TOTAL |
|---|---|---|---|---|
| CARS | 78.93 | 15.88 | 0.36 | 95.2 |
| 1/2 TONS | 42.15 | 8.04 | 0.3 | 50.5 |
| OTHERS | 21.79 | 6.23 | 0.19 | 28.2 |
| STRAIGHT TRUCKS | 77.68 | 13.99 | 0.93 | 92.6 |
| ARTICULATED TRUCKS | 148.28 | 34.53 | 3.84 | 186.7 |

(1) Calculated using data in Table 3.4 and Table 3.8.

FIGURE 3.10
ACCIDENT INVOLVEMENTS PER 1000 SASK.
REGISTERED VEHICLES BY SEVERITY AND TYPE



## 3.4 Summary

Articulated trucks are involved in a relatively small percentage of total accidents but tend to have a disproportionate share of the serious accidents and fatalities. These serious truck accidents tend to occur in rural areas more often than urban areas.

## 3.5 Exposure

While the preceding sections provide some insight into the large truck accident experience, they do not give the complete picture. Articulated trucks on average travel 5-10 times further each year relative to other vehicle types. It is appropriate, therefore, to include exposure (i.e. total distance travelled) as a parameter in determining the relative accident experience of articulated trucks.

Exposure can be integrated into the analysis by using accident rates (i.e. accidents per million vehicle kilometers travelled) as the measurement criterion as opposed to simply the total number of vehicles involved in accidents, total number of accidents or the number of accidents per 1000 registered vehicles.

In order to calculate these accident rates, information on the total distance travelled is required. This is a challenge because of the limited availability of data on total travel and travel by particular vehicle types.

The methodology used here can be shown conceptually as:

$$\text{Accident Rate} = \frac{\text{Number of Accidents}}{\text{Total Vehicle Travel (million vehicle km)}}$$

The challenge is to develop appropriate estimates for total travel by articulated trucks using available data. This data is limited to vehicle count and vehicle classification surveys at various locations throughout the highway network in Saskatchewan.

Saskatchewan Highways count total vehicles at 26 permanent counter locations on the highway system on a continuous basis each year. These continuous counts are complemented by periodic 72 hour counts at numerous temporary locations. The information provided by these counting programs provide estimates of the Average Annual Daily Traffic (AADT) on each control section within the Saskatchewan highway network. Estimates of total travel by all vehicles on the Saskatchewan highway network can therefore be developed by combining the estimates of total traffic (i.e. AADT) with the length of each control section.

Classification counts that provide data by major vehicle type (i.e. cars, 1/2 tons, truck, RV's and others) were available for 93 sites throughout the province in 1983. Data from a special classification survey at 26 locations in 1986 provided further detail with respect to the portion of the total trucks that were articulated trucks. There were also classification counts at all ATR locations but these were inappropriate for present purposes because they did not provide sufficient detail with respect to classification of single versus double trailer units or type of double trailer (i.e. A-Train versus B-Train versus C-Train). A method using available data which had sufficient detail was therefore developed and used in this analysis as described below.

As noted above, total travel by all vehicles on the highway network can be estimated as follows:

$$TT = \sum_{i}(AADT_i * L_i) \text{ for } i = 1,2,3 \ldots n$$

where

TT = total travel by all vehicles on Saskatchewan highways

$AADT_i$ = average annual daily traffic on control section $i$ (for $i = 1,2 \ldots n$).

$L_i$ = length of control section $i$ (for $i = 1, 2 \ldots n$).

These estimates of total travel by all vehicles can then be factored by the percent of total traffic that is by trucks (straight trucks and articulated trucks) as determined by the

classification counts at 93 locations. These percentages can be estimated using available data as follows:

$$\%TTT = \sum_i \left( \frac{AADT_i * L_i * T_i}{\sum_i (AADT_i * L_i)} \right)$$

where

%TTT = Percent of total travel by all vehicles on Saskatchewan highways that is made by trucks.

$AADT_i$ = Average Annual Daily Traffic on control section $i$ (for $i$ = 1, 2 ....n)

$L_i$ = Length of control section $i$ (for $i$ = 1, 2 ...n)

$T_i$ = % of total traffic on control section $i$ that is trucks (for $i$ = 1, 2 .... n).

The special classification surveys at 26 locations provides information on the percent of all trucks that are articulated trucks. Therefore this information can be combined with the above to provide an estimate of the percent of total travel by trucks which is by articulated trucks as follows:

$$\%TTTS = \sum_i \left( \frac{AADT_i * L_i * T_i * S_i}{\sum_i (AADT_i * L_i)} \right)$$

where

%TTTS = Percentage of total travel by trucks that is by articulated trucks.

$AADT_i$ = Average Annual Daily Traffic for control section $i$ (for $i$ = 1, 2 ... n)

$T_i$ = % of total traffic on control section $i$ that is trucks (for $i$ = 1, 2 ... n)

$S_i$ = % of total trucks on control section $i$ that is articulated trucks (for $i$ = 1, 2 ... n)

Therefore, if "A" equals the number of accidents per year involving articulated trucks on the highway network, and "A.R." equals the accident rate for articulated trucks, then:

$$A.R. = \frac{A}{TT * TTT * TTTS}$$

where

TT = total travel by all vehicles on Saskatchewan highways

TTT = % of total travel by all vehicles that is made by trucks

TTTS = % of total truck travel that is made by articulated trucks

or

$$A.R. = \frac{A}{\left[\sum_i (AADT_i * L_i)\right] * \left[\frac{\sum (AADT_i * L_i * T_i)}{\left[\sum_i (\sum (AADT_i * L_i))\right]}\right] * \left[\frac{\sum (AADT_i * L_i * T_i * S_i)}{\left[\sum_i (\sum (AADT_i * L_i))\right]}\right]}$$

## 3.6 Sensitivity Analysis

Given that there is uncertainty inherent in the various data used to calculate accident rates, a sensitivity analysis would be informative. Sensitivity analysis are designed to assess the implications of variations in input parameters on an outcome, in this case, accident rates.

One way to test the sensitivity of accident rates to each of the input parameters is to first, estimate the maximum, minimum and median value for each parameter, and then hold all of the input parameters constant at their median values, except one, and make successive calculations (using the above equation) by varying the value of the parameter being tested across its' range of uncertainty (from its' minimum possible value to its' maximum possible value). By so doing one can determine the degree to which the measurement criterion (in this case, accident rate) varies as the variable being tested varies, all else being equal. By comparing degrees of variation in accident rates for different input parameters being tested, the impact of uncertainties in input parameters on calculated accident rates can be assessed. This will show which input parameters have significant impact on the accident rates and allow the analysis to concentrate on reducing the negative impacts of uncertainties in these parameters.

In order to undertake sensitivity analysis, it is necessary to estimate the range of uncertainty applicable to each of the input parameters. This is best done using empirical data. In some cases such data is not available and informed judgement must be used.

The input parameters for determining accident rates using the previously described procedure include:

$A$ = Number of accidents

$AADT_i$ = Average annual daily traffic for control section $i$

$L_i$ = length of control section $i$

$T_i$ = percent trucks on control section $i$

$S_i$ = percent of total trucks that are articulated trucks on control section $i$.

Uncertainties in the number of accidents (A), relate largely to the potential for unreported accidents. Empirical evidence on this is limited. However, information made available during the course of this project indicated a 20% nonreporting rate.

It is unlikely that major accidents go unreported because vehicle owners must have verification of having reported the accident to police and/or Saskatchewan Government Insurance before a body shop can perform required repairs. This constraint could be bypassed by some (large) firms that have in-house capabilities to repair and/or rebuild trucks; however, such nonreporting would preclude collecting insurance. In addition, reporting is a requirement of the law. As a result, the problem of nonreporting is probably associated with minor single vehicle accidents which individual truckers view as being in their interest to handle themselves. The limited data suggests this is indeed the case. Given that most accidents are in fact minor accidents, it is

conceivable that 10% to 20% of all accidents go unreported.

For present purposes, the maximum value for the number of accidents (A) was set at 120% of the most likely value. The most reasonable estimate for the median value of number of accidents is the actual number of accidents reported. Since it is unlikely that people report accidents that do not occur, the minimum value was also set at the number reported.

The uncertainty in the value for AADT varies with counting method (permanent versus 72 hour counts) and location (high versus low volume roads). Permanent counters tend to be located on high volume roads and the 72 hour counts tend to be used on low volume roads. Again there is no empirical evidence available to quantify the degree of uncertainty, therefore informed judgement was used as noted below.

| AADT | Most Likely | Minimum | Maximum |
|---|---|---|---|
| > 500 vehicles/day | 0% | -5% | +5% |
| <500 >250 vehicles/day | 0% | -10% | +10% |
| >250 vehicles/day | 0% | -20% | +20% |

The percent trucks in the traffic stream is highly variable depending upon location, time of day, and season. There is some limited empirical evidence on the variability in this particular

parameter. Figure 3.11 shows a frequency distribution for the percent trucks as obtained from the vehicle classifications taken at 93 sites used in this analysis. Since these classification counts were taken at different locations and on different days, the frequency distribution in Figure 3.11 gives a feel for the magnitude of the variations in percent trucks across location and to some extent, across time period.

Since the classification counts were 12 hour counts taken from 8 AM to 8 PM, they do not fully represent the variation across time during the full day. Further, because the counts were not done uniformly throughout the year, they may not fully represent the variability across seasons.

Figure 3.12 gives some insight into the variations across time periods within the day. As shown, the distribution of truck traffic within the day is highly variable. Unfortunately no data was available for inter-seasonal variations.

In spite of the above limitations, the frequency distributions in Figure 3.12 do give a feel for the order of magnitude of variations in the number of trucks in the traffic stream as a function of time of day and, therefore, have some use in terms of the sensitivity analysis. From Figure 3.11, the maximum, minimum and most likely values for the percent trucks in the traffic stream were estimated to be 30%, 6% and 15% respectively.

FIGURE 3.11
FREQUENCY DISTRIBUTION OF %
TRUCKS IN THE TRAFFIC STREAM

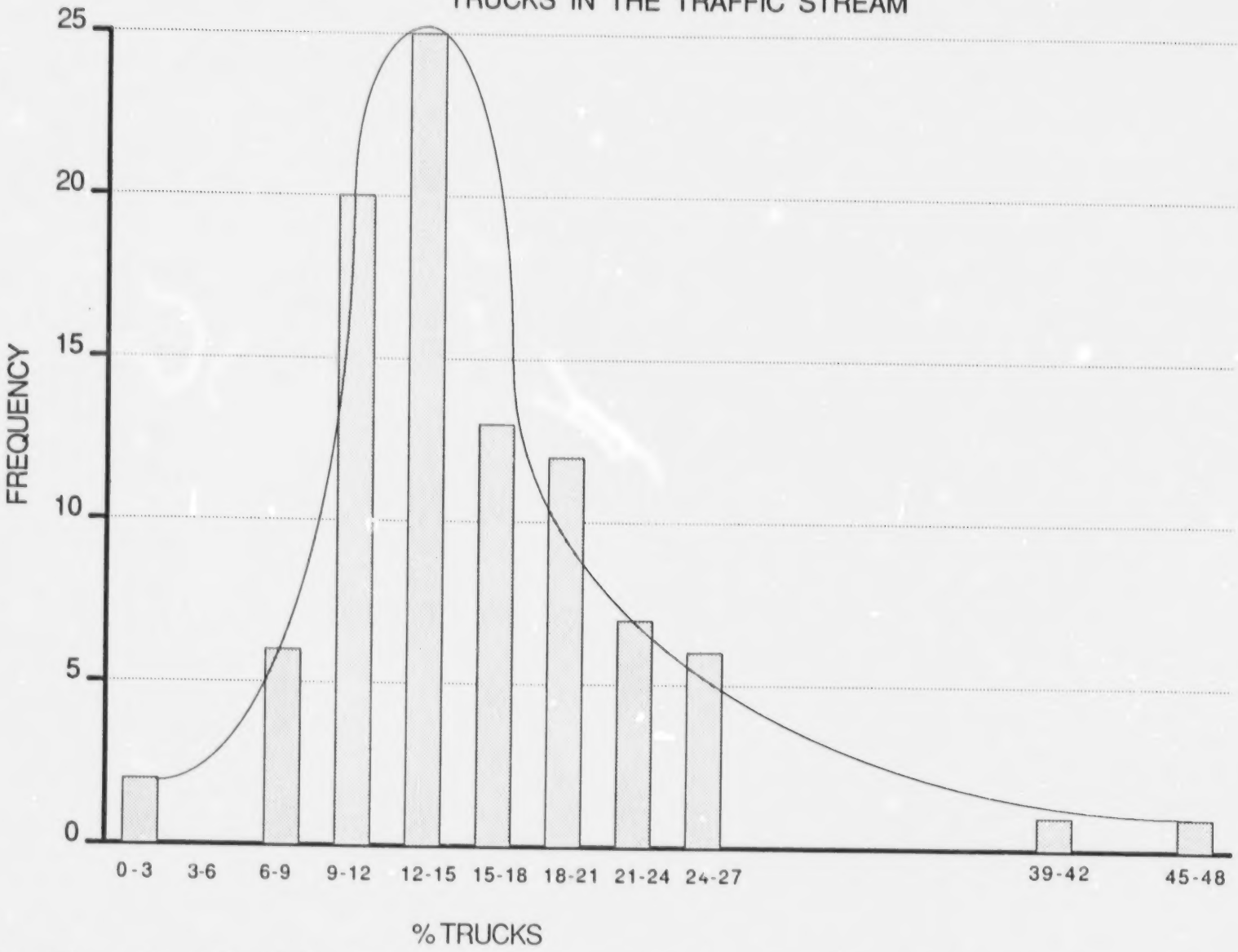
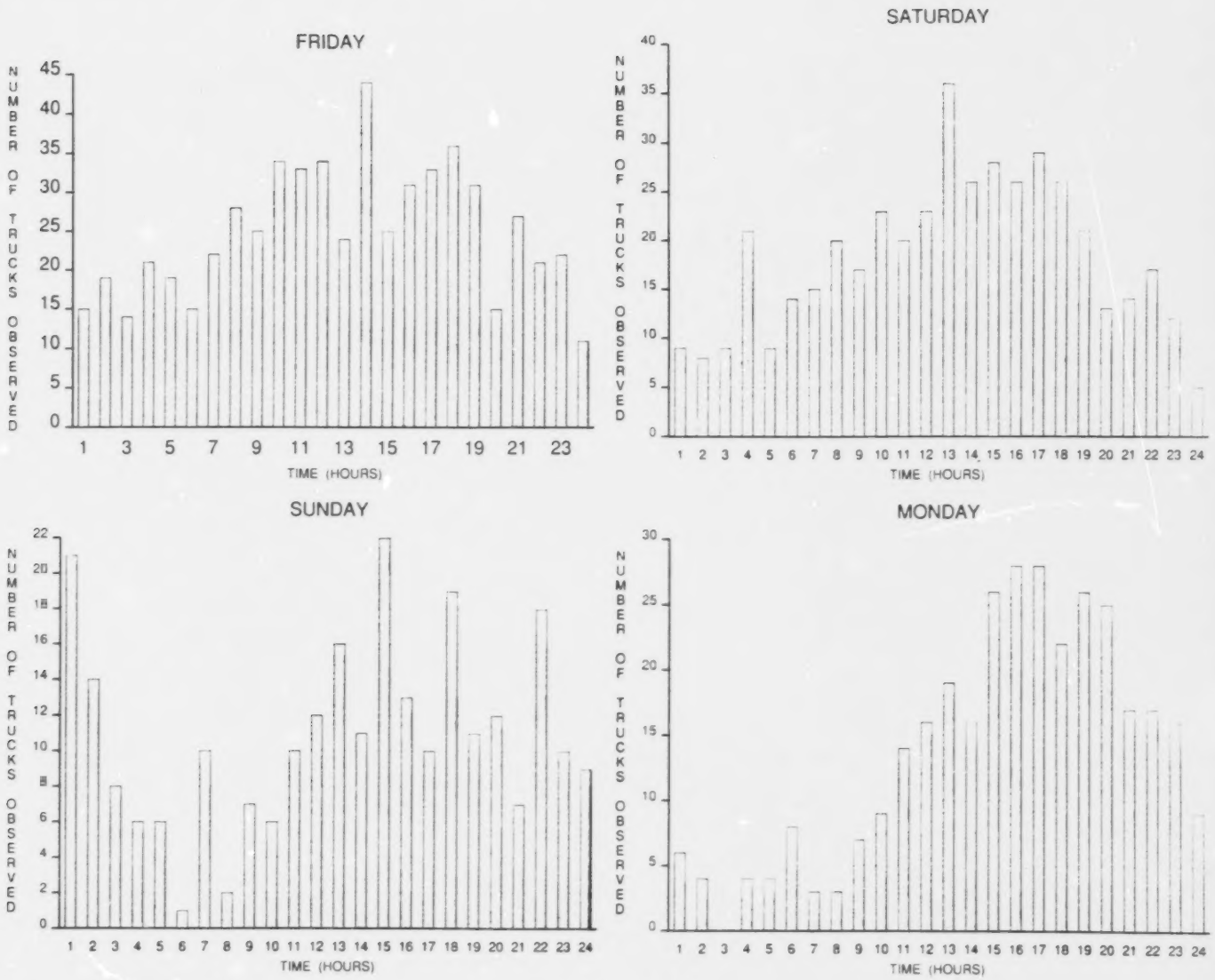


FIGURE 3.12
TRUCK FREQUENCY VERSUS TIME FOR HIGHWAY #1



The percent trucks that are articulated also varies depending on location, time, etc. Figure 3.13 shows a frequency distribution of the percent trucks that are articulated trucks for the 26 sites surveyed and used in this analysis. From Figure 3.13, the maximum, minimum and most likely values for the percent trucks that are articulated trucks was estimated to be 92%, 60%, and 75% respectively.

The above noted maximum, minimum and most likely values for each parameter were used to conduct a sensitivity analysis of accident rate in relation to the number of accidents, AADT, %trucks, %articulated, and total travel by all vehicles. The results are summarized in Table 3.10 and illustrated in Figure 3.14. From Figure 3.14, it can be seen that accident rates are:

1) Highly sensitive to variations in:
   - o % traffic that is trucks;

2) Moderately sensitive to variations in:
   - o % of trucks that are articulated trucks;
   - o number of accidents involving articulated trucks;
   - o total travel by all vehicles on the highway system;

3) Relatively insensitive to variations in:
   - o average annual daily traffic on individual control sections.

These results are intuitively appealing in that a review of the equation relating accident rate to the number of accidents, AADT, % trucks, % articulated trucks, and total travel indicates that

FIGURE 3.13
FREQUENCY DISTRIBUTION OF %
TRUCKS THAT ARE ARTICULATED

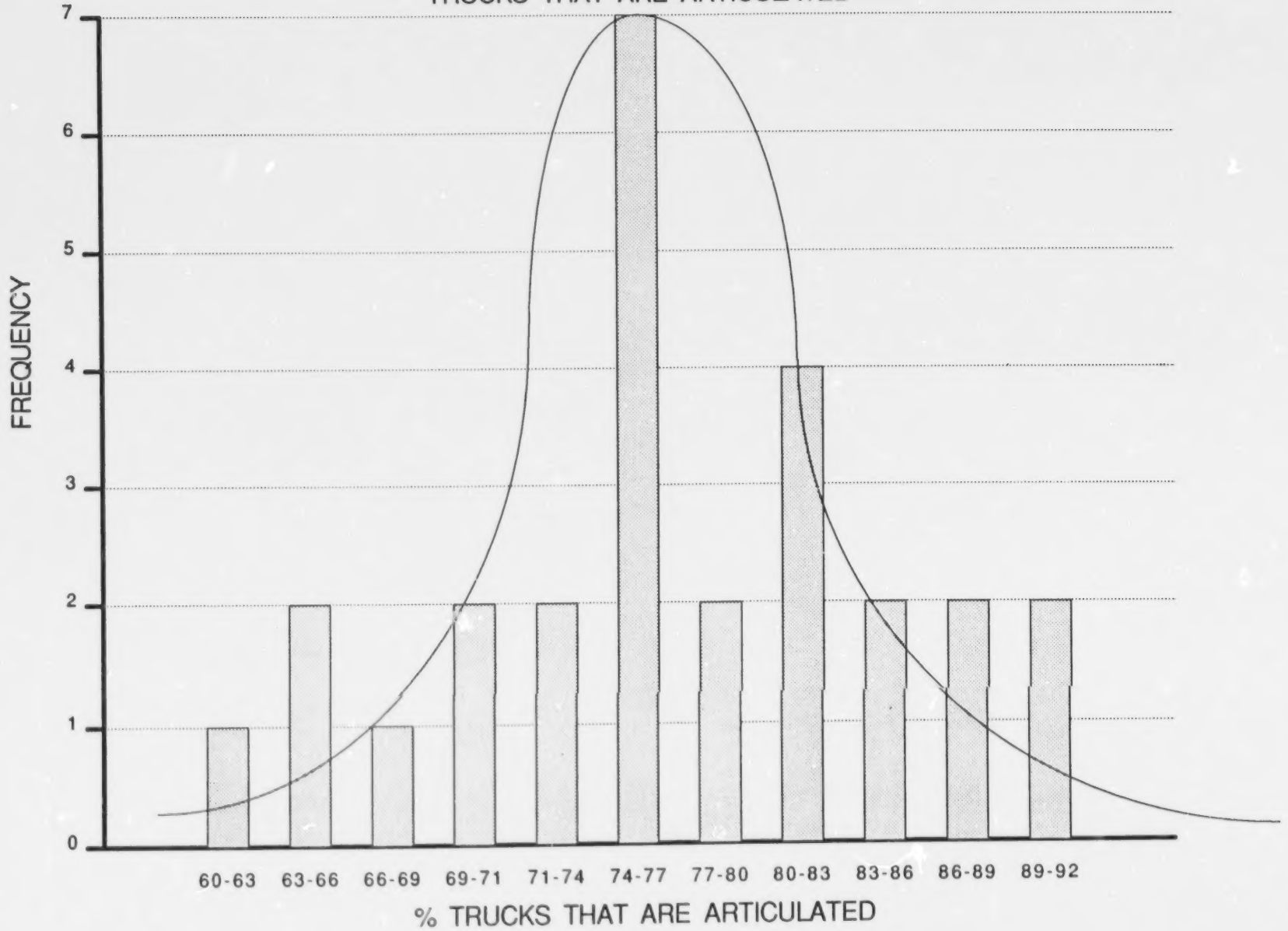


TABLE 3.10
SUMMARY OF SENSITIVITY ANALYSIS

| PARAMETER | SYMBOL | RANGE OF VALUES (1) | | | ACCIDENTS / 10E6 VEH. KM | | |
|---|---|---|---|---|---|---|---|
| | | MEDIAN | MAX | MIN | BASE | MAX | MIN |
| NO. OF ART. TRUCK ACCIDENTS ON SASK. HWYS PER YEAR (2) | A | 426 | 120% | 100% | .713 | .855 | .713 |
| % TRAFFIC THAT IS TRUCKS | T | 15 | 30 | 6 | .713 | 1.782 | .356 |
| % TRUCKS THAT ARE ARTICULATED | S | 75 | 60 | 92 | .713 | .891 | .581 |
| ADT FROM VOLUME COUNT SURVEY AADTI (3) | | | | | | | |
| > 500 | AADTi | 100% | 105% | -105% | .713 | .713 | .712 |
| 250-500 | AADTi | 100% | 110% | -110% | .713 | .713 | .712 |
| < 250 | AADTi | 100% | 120% | -120% | .713 | .714 | .712 |
| TOTAL TRAVEL BY ALL VEHICLES ON SASK. HWYS (4) (10E6 KM) | TT | 5276 | 5804 | 4748 | .713 | .792 | .648 |

NOTE:

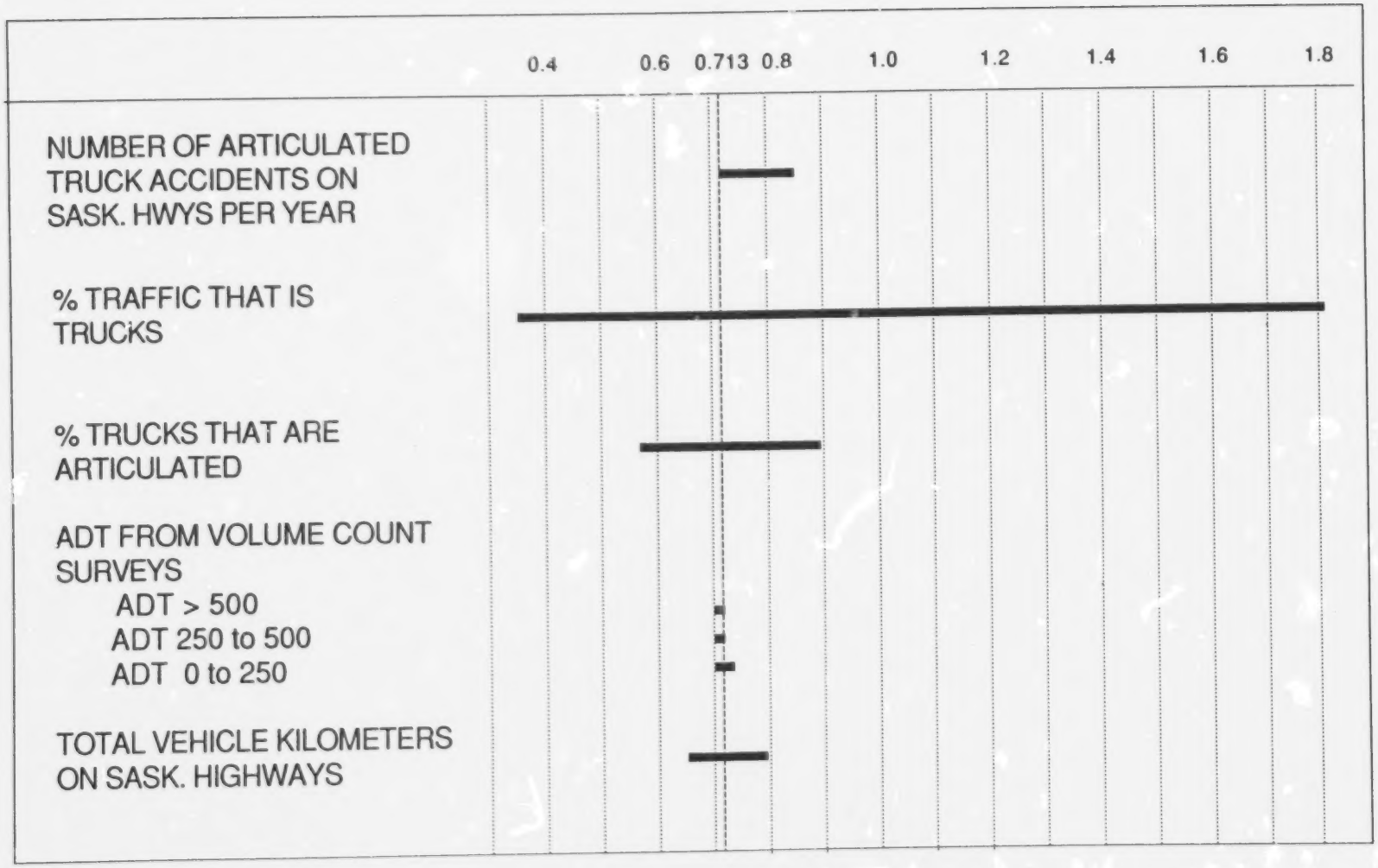
(1) THE MAXIMUM AND MINIMUM VALUES FOR THE INPUT PARAMETERS ARE THE BEST ESTIMATES FROM THE AVAILABLE DATA

(2) NOTE THESE ARE ARTICULATED TRUCK ACCIDENTS ON THE PROVINCIAL HIGHWAY SYSTEM IN 1985 ONLY. THIS DOES NOT INCLUDE RURAL ROADS OR URBAN STREETS.

(3) THE TRAFFIC VOLUMES WHERE BROKEN DOWN INTO THREE CATEGORIES BECAUSE THE UNCERTAINTY VARIES BETWEEN CATEGORIES DUE TO DATA COLLECTION METHODS

(4) TOTAL VEHICLE TRAVEL ON SASKATCHEWAN HIGHWAYS BY ALL VEHICLES. THIS RANGE IS TYPICAL OF THE VARIANCE FROM YEAR TO YEAR THAT MIGHT BE EXPECTED.

FIGURE 3.14
DETERMINISTIC SENSITIVITY
(Accidents / Million Vehicle Km)



accident rate is a linear function of each of these parameters. That is, if the number of accidents were to double, all else equal, the accident rate would double. If traffic were to double, the accident rate would become half its previous value. Similarly, if % trucks in the traffic stream, % trucks that are articulated, or total travel were to double, accident rates would be reduced by a factor of two.

In the context of the above, the reason accident rate is more sensitive to some parameters than others is because the relative degree of uncertainty is larger for some parameters than others. To illustrate, the uncertainty in the number of accidents is only 20% relative to a factor of 2 in the % of the traffic that is trucks (i.e. our best estimate is that 15% of the traffic is trucks, but it could be as high as 30% or as low as 6%).

Given that accident rate is a linear function of each of these parameters, it is obvious that it must be most sensitive to the parameters for which the relative uncertainty is the largest.

From this, it can be concluded that the critical factors in the determination of accident rates are the highly and moderately sensitive parameters: % trucks in the traffic stream, % trucks that are articulated, the number of accidents, and total travel.

These sensitive and moderately sensitive factors may vary from one highway agency to another because the uncertainty associated with each parameter may vary between agencies. For example, if the percent trucks can be shown to have less uncertainty than assumed in our calculations (i.e. Table 3.10 minimum and maximum values), because of highly reliable data, then it will become a less sensitive parameter.

## 3.7 Probabilistic Model

The deterministic model detailed in the previous section was used to estimate accident rates for articulated trucks on the Saskatchewan highway system. The accident rate determined for these articulated trucks was 0.713 accidents per million km when the most likely values for all input parameters were used. It was also shown that these rates could vary from 0.356 to 1.78 by varying any one of the parameters to which accident rates are sensitive.

It would be of considerable interest to determine the combined effect of varying a number of sensitive parameters at one time as opposed to varying them one at a time, as was done above. This type of analysis is made possible using a probabilistic approach.

A probabilistic model was formulated for the four most sensitive parameters. This model is illustrated conceptually in Figure

3.15. The probability distributions for the sensitive parameters were combined as illustrated to provide a probability distribution for accident rates. The expected value as provided by the probabilistic model is equivalent to the value provided by the deterministic model when the most likely parameters are used.

Figures 3.16 and 3.17 illustrate the results of the probabilistic model in terms of a cumulative probability distribution and a probability density function over accident rate respectively. It can be seen that the expected accident rate for articulated trucks on Saskatchewan highways is 0.713 but could be as low as 0.5 or as high as 1.1 given the uncertainty inherent in the input data. The range defined by the .5 to 1.1 accidents per million vehicle km of travel can be loosely considered a 95% confidence interval. That is, given the inherent uncertainty in input parameters, it is unlikely that the accident rate is less than 0.5 or greater than 1.1.

## 3.8 Comparison of Accident Rates

Accident rates for all vehicles have been determined by Saskatchewan Highways and Transportation for all roads (urban and rural) as well as by road type (highway, urban and rural road). These rates for 1983-1986 are summarized in Table 3.11.

FIGURE 3.15

PROBABLISTIC MODEL

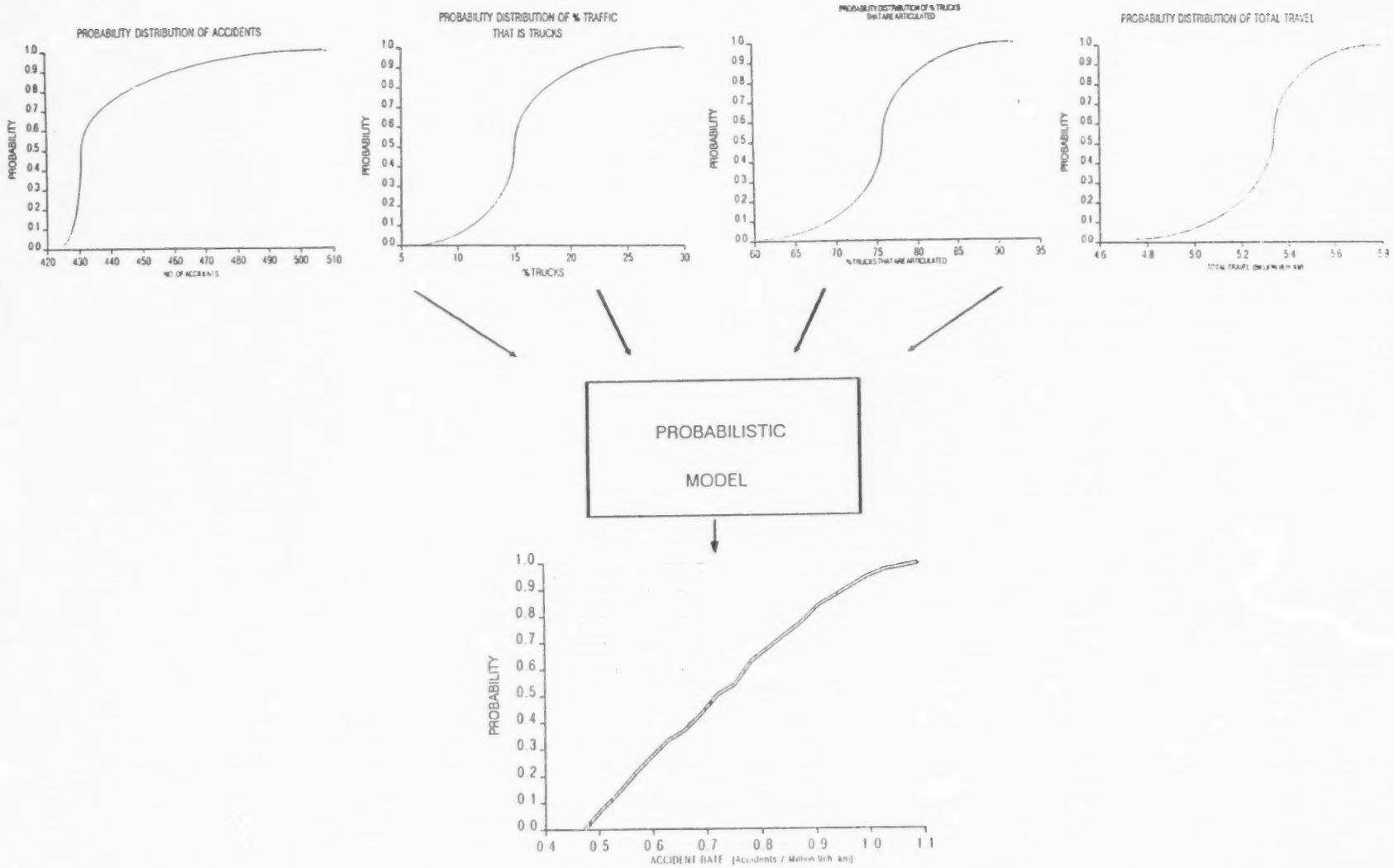


FIGURE 3.16
CUMULATIVE PROBABILITY DISTRIBUTION OF ACCIDENT RATES
FOR ARTICULATED TRUCKS ON SASKATCHEWAN HIGHWAYS

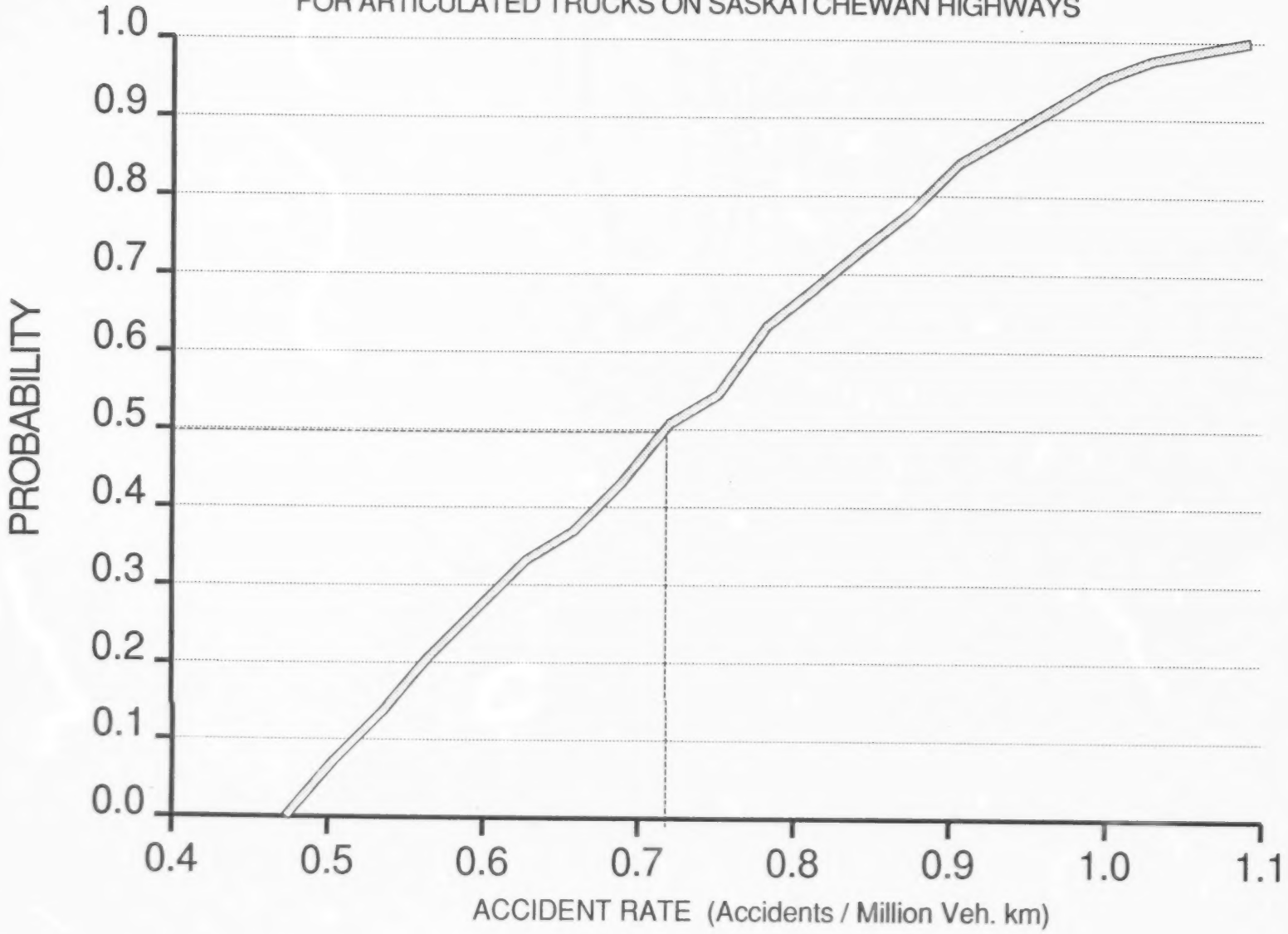


FIGURE 3.17
PROBABILITY DENSITY FUNCTION
ACCIDENT RATES FOR ARTICULATED TRUCKS
ON SASKATCHEWAN HIGHWAYS

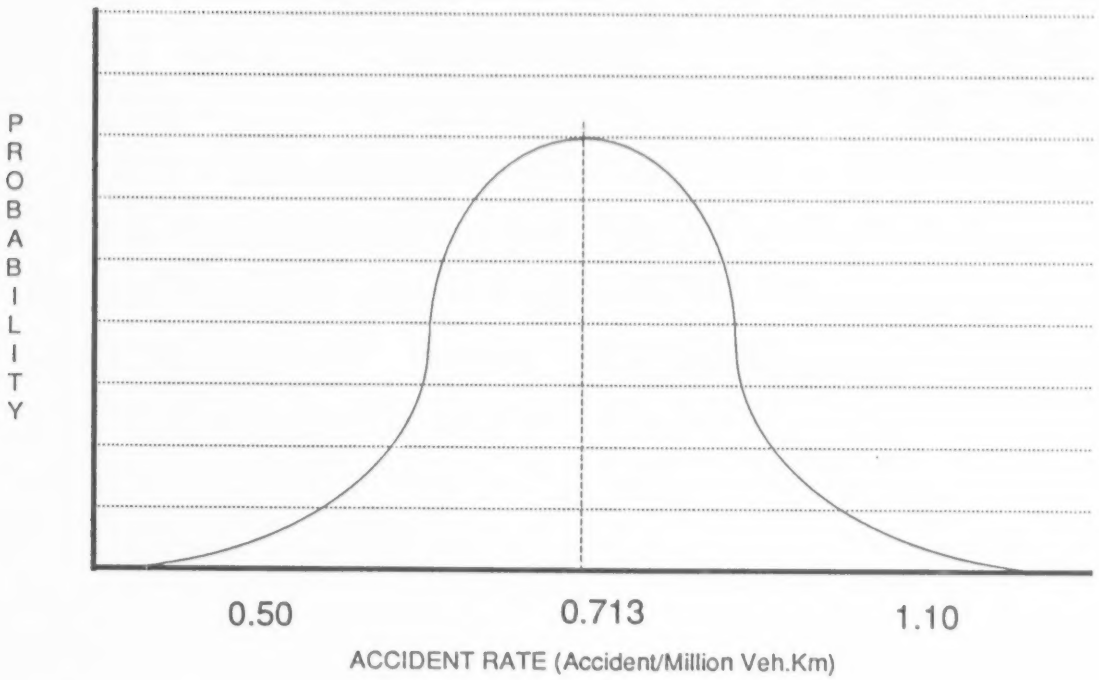


TABLE 3.11

ACCIDENT RATE IN SASKATCHEWAN BY ROAD TYPE

| | 1983 | 1984 | 1985 | 1986 |
|---|---|---|---|---|
| Accident Rate in Saskatchewan(1) (Accidents/million vehicle km) | 4.07 | 3.26 | 3.22 | 3.17 |
| Accident Rate on Saskatchewan Highways(2) (Accidents/million vehicle km) | 1.02 | .88 | .90 | .81 |
| Accident Rate in Urban Areas(3) (Accidents/million vehicle km) | 8.90 | 8.86 | 8.74 | 8.86 |
| Accident Rate on Rural Roads(4) (Accidents/million vehicle km) | 2.66 | 2.16 | 2.18 | 2.13 |

Source: Saskatchewan Highways and Transportation

(1) This includes total reported accidents in Saskatchewan and includes both urban and rural areas
Note: Reporting threshold changed from $200 to $500 in January 1984

(2) This includes accidents and travel only on the provincial highway system

(3) This includes all accidents and travel in all urban areas in Sasktchewan

(4) This includes all accidents and travel on rural roads in Saskatchewan

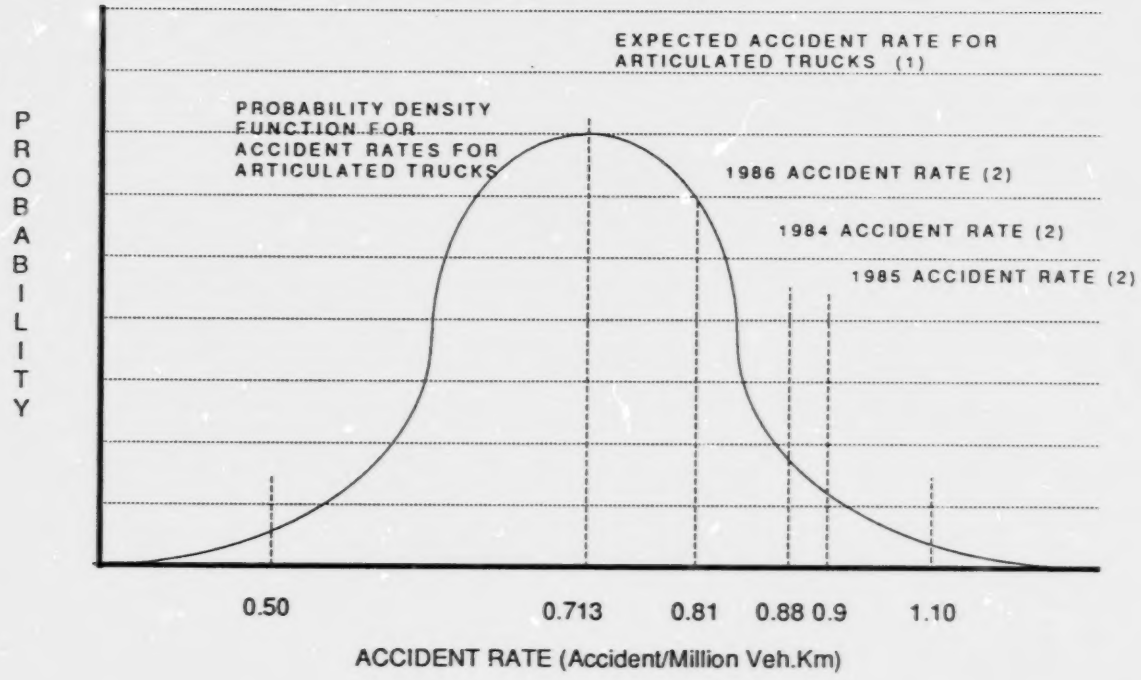
It can be seen that the accident rate for all vehicles travelling on all roads in Saskatchewan has been between 3.17 and 4.07 accidents per million vehicle kilometres over the 1983-1987 period. It is important to note that the threshold on a reportable accident was increased from $200 to $500 in January 1984. This accounts for the sharp decrease in the accident rate between 1983 and 1984. Since 1984, (with the common definition of an accident) the system average has been in the 3.17 to 3.26 accidents per million vehicle km range.

It is also noted that the accident rate for all vehicles on the provincial highway system has varied from 0.81 to 1.08 over the 1983-1986 period and 0.81 to 0.90 over the 1984-1986 period.

The 1984-1986 accident rates for all vehicles on the provincial highway system are plotted in Figure 3.18 on the probability density function for accident rates for articulated trucks on Saskatchewan highways as determined using the probabilistic model developed in Section 3.7. From this Figure, it is observed that the estimate for the accident rate for articulated trucks operating on Saskatchewan highways compares favorably with the accident rate for all vehicles operating on Saskatchewan highways. That is, from Figure 3.18 articulated trucks clearly do not appear to have a higher accident rate than the vehicle population generally and in fact, may even have a somewhat lower rate (i.e. 0.713 versus 0.81, 0.88, and 0.91).

FIGURE 3.18

PROBABILITY DENSITY FUNCTION
ACCIDENT RATES FOR ARTICULATED TRUCKS
ON SASKATCHEWAN HIGHWAYS




(1) AS DETERMINED FROM THE PROBABILISTIC MODEL.

(2) ALL VEHICLES ON PROVINCIAL HIGHWAYS, ALL FATAL, INJURY AND PROPERTY DAMAGE ACCIDENTS INVOLVING DAMAGES OF GREATER THAN $500.

As to whether or not it can actually be concluded that large trucks have a lower accident rate than other vehicles, it is difficult to say from the perspective of strict statistical significance. This inability to determine statistically significant differences is attributable to the large uncertainty inherent in the estimate of the accident rate of articulated trucks due to data limitations (i.e. % trucks in the traffic stream).

## 3.9 Summary

There are a number of ways to measure vehicle accident experience. In the previous sections, accident experience was measured by:

1) the total number of accidents,
2) the total number of vehicles involved in accidents,
3) the number of vehicles involved in accidents per 1000 registered vehicles, and
4) the number of accidents per million vehicle km of travel.

While articulated trucks are involved in relatively few accidents in total number, they are involved in a disproportionate number relative to their proportion in the total vehicle fleet and are involved in a disproportionate number of serious accidents

particularly in rural areas. When the accident experience was tempered with exposure data, the accident experience of articulated trucks operating on Saskatchewan highways was found to be comparable to the total vehicle fleet operating on the highway system. That is, when distance travelled was considered, articulated trucks did not experience substantially more or less accidents per unit of travel on the highway system than the vehicle fleet as a whole.

## Chapter 4: Fleet Specific Experience

### 4.1 Introduction

This project had a particular interest in examining the accident experience of double trailer units versus single trailer units, as well as the accident experience of A, B, and C-Train configurations. It was not possible to explore this subject using the traffic accident database (the required detail was not available). As a consequence, a number of individual fleet operators were approached for their assistance. Accident and exposure data were obtained and accident rates calculated for singles versus doubles and for A, B, and C-Train configurations on a fleet specific basis. The level of detail varied from carrier to carrier because the level of detail in the data available varied from carrier to carrier. Not all of this detail can be described here because of the need to maintain confidentiality.

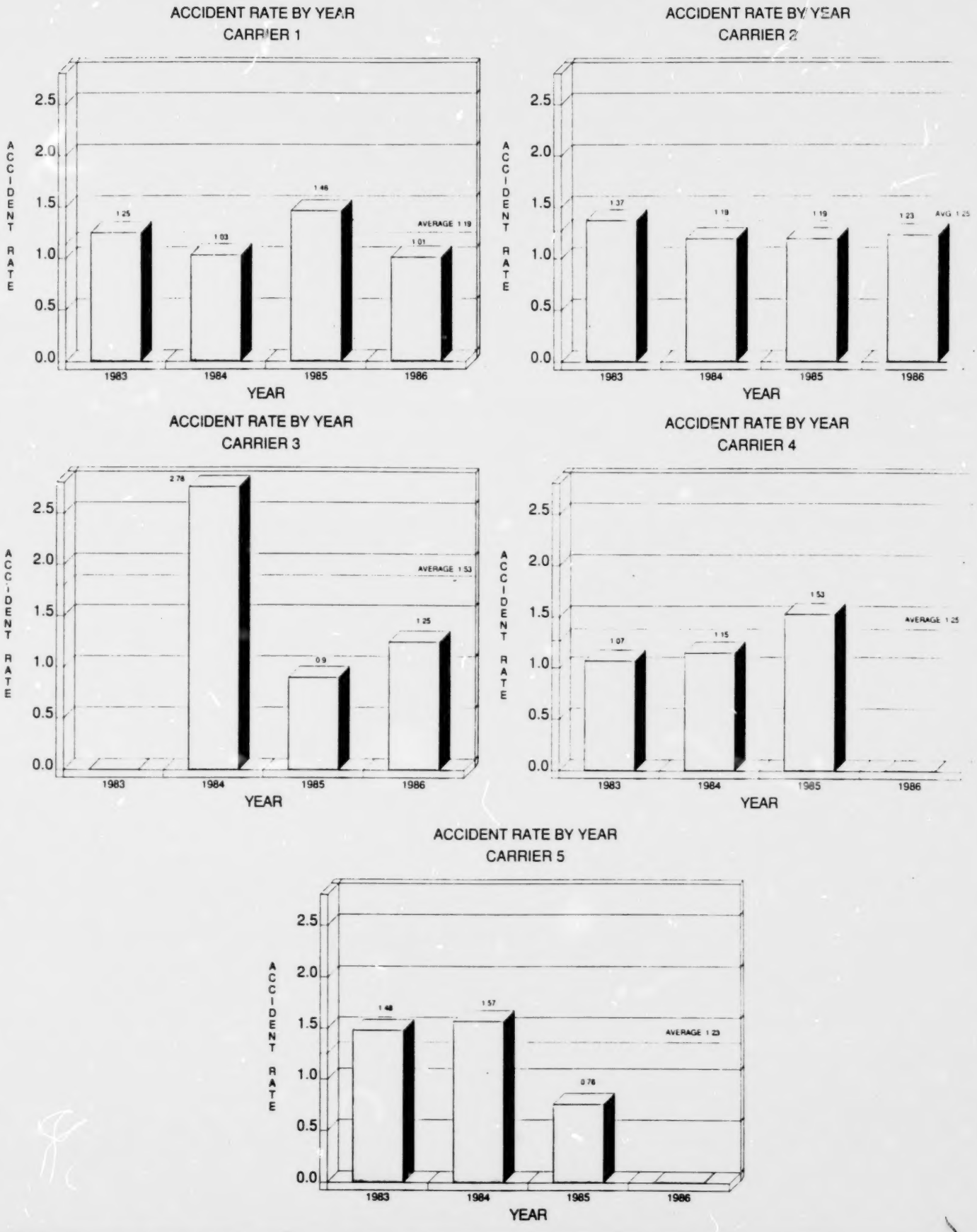
### 4.2 Fleet Specific Accident Experience

Table 4.1 and Figure 4.1 show the overall accident experience of five large fleets based in western Canada. The fleet specific accident rates illustrated are of interest in terms of both their absolute values (i.e. number of accidents per million vehicle km) as well as for their comparative values (i.e. between carriers,

TABLE 4.1
ACCIDENT EXPERIENCE OF FIVE CARRIERS
OPERATING IN WESTERN CANADA
SUMMARY

| CALCULATED ACCIDENT RATES | CARRIER 1 | | | | | CARRIER 2 | | | | | CARRIER 3 | | | | | CARRIER 4 | | | | | CARRIER 5 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1983 | 1984 | 1985 | 1986 | TOTAL | 1983 | 1984 | 1985 | 1986 | TOTAL | 1983 | 1984 | 1985 | 1986 | TOTAL | 1983 | 1984 | 1985 | 1986 | TOTAL | 1983 | 1984 | 1985 | 1986 | TOTAL |
| **SINGLES** | | | | | | | | | | | | | | | | | | | | | | | | | |
| PROPERTY DAMAGE | 1.68 | 1.13 | 1.80 | 1.25 | 1.48 | 1.04 | 0.60 | 0.51 | 0.94 | 0.79 | - | - | - | - | - | - | - | - | - | 0.00 | - | - | - | - | - |
| INJURY | 0.23 | 0.24 | 0.27 | 0.19 | 0.23 | 0.12 | 0.15 | 0.17 | 0.38 | 0.19 | - | - | - | - | - | - | - | - | - | 0.00 | - | - | - | - | - |
| FATALITY | 0.00 | 0.07 | 0.17 | 0.00 | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | - | - | - | - | - | - | - | - | - | 0.00 | - | - | - | - | - |
| TOTAL | 2.05 | 1.51 | 2.45 | 1.44 | 1.88 | 1.15 | 0.75 | 0.68 | 1.32 | 0.98 | - | - | - | - | - | - | 1.07 | 1.27 | - | 1.16 | - | - | - | - | N/A |
| **DOUBLES** | | | | | | | | | | | | | | | | | | | | | | | | | |
| PROPERTY DAMAGE | 0.51 | 0.64 | 0.76 | 0.70 | 0.66 | 1.17 | 0.74 | 0.91 | 0.85 | 0.91 | - | 1.97 | 0.60 | 0.98 | 1.11 | - | - | - | - | 0.00 | - | - | - | - | - |
| INJURY | 0.20 | 0.07 | 0.11 | 0.02 | 0.10 | 0.10 | 0.40 | 0.16 | 0.13 | 0.20 | - | 0.66 | 0.30 | 0.27 | 0.38 | - | - | - | - | 0.00 | - | - | - | - | - |
| FATALITY | 0.04 | 0.00 | 0.02 | 0.02 | 0.02 | 0.05 | 0.05 | 0.00 | 0.09 | 0.05 | - | 0.00 | 0.00 | 0.00 | 0.00 | - | - | - | - | 0.00 | - | - | - | - | - |
| TOTAL | 0.75 | 0.72 | 0.99 | 0.74 | 0.81 | 1.32 | 1.19 | 1.07 | 1.16 | 1.18 | - | 2.76 | 0.90 | 1.25 | 1.53 | - | 1.22 | 1.70 | - | 1.48 | 1.48 | 1.57 | 0.76 | - | 1.23 |
| **OVERALL ACCIDENT RATE** | | | | | | | | | | | | | | | | | | | | | | | | | |
| PROPERTY DAMAGE AR'S | 0.96 | 0.83 | 1.10 | 0.91 | 0.95 | 1.20 | 0.82 | 0.99 | 0.90 | 0.98 | - | 1.97 | 0.60 | 0.98 | 1.11 | - | - | - | - | ERR | - | - | - | - | - |
| INJURY AR'S | 0.22 | 0.13 | 0.17 | 0.07 | 0.14 | 0.14 | 0.33 | 0.17 | 0.18 | 0.20 | - | 0.66 | 0.30 | 0.27 | 0.38 | - | - | - | - | ERR | - | - | - | - | - |
| FATALITY AR'S | 0.02 | 0.02 | 0.07 | 0.01 | 0.03 | 0.04 | 0.04 | 0.00 | 0.07 | 0.04 | - | 0.00 | 0.00 | 0.00 | 0.00 | - | - | - | - | ERR | - | - | - | - | - |
| TOTAL | 1.25 | 1.03 | 1.46 | 1.01 | 1.19 | 1.37 | 1.19 | 1.19 | 1.23 | 1.25 | - | 2.76 | 0.90 | 1.25 | 1.53 | 1.07 | 1.15 | 1.53 | - | 1.25 | 1.48 | 1.57 | 0.76 | - | 1.23 |
| **DOUBLES BY CONFIGURATION** | | | | | | | | | | | | | | | | | | | | | | | | | |
| A-TRAIN | 0.74 | 0.59 | 0.85 | 0.51 | 0.67 | 1.46 | 1.08 | 1.37 | 1.15 | 1.45 | - | 2.73 | 0.90 | 1.25 | 1.52 | - | 0.00 | 0.55 | - | 0.25 | 1.48 | 1.57 | 0.76 | - | 1.23 |
| B-TRAIN | 0.52 | 0.50 | 0.98 | 1.03 | 0.76 | 1.44 | 0.73 | 0.87 | 0.80 | 0.96 | - | - | - | - | - | - | 1.45 | 1.88 | - | 1.68 | - | - | - | - | - |
| C-TRAIN | 3.61 | 1.19 | 1.22 | 1.08 | 1.20 | 0.39 | 0.57 | 0.88 | 1.47 | 0.88 | - | - | - | - | - | - | 1.73 | 1.97 | - | 1.87 | - | - | - | - | - |

FIGURE 4.1
ACCIDENT EXPERIENCE OF 5 CARRIERS



singles versus doubles, and A versus B versus C-Trains).

Considerable care must however be taken in making comparisons because not all things are equal on a comparative basis. That is, there are reasons other than vehicle type (i.e. single versus double or A versus B versus C-Train) which could be expected to contribute to differences in accident experience. To illustrate, a number of reasons for these differences are discussed below.

### 4.2.1 Definition of Accident

For carriers 1 through 4, an accident was defined as any incident resulting in property damage of any amount, injury, or fatality. There was no threshold or deductible - all accidents are included.

For carrier 5 the definition of an accident was constrained by the availability of data, which was a function of the severity of the accident and the individuals involved. All data was obtained from the files of the insurance company. In 1983 and 1984, the deductible on reportable accidents was $2000. This was raised to $5000 in 1985. Thus if a vehicle was involved in an accident that resulted in only minor damage (i.e. obviously less than the deductible) the accident may not have been brought to the attention of the insurance company and there would not have been a file prepared. Such accidents are not included in this

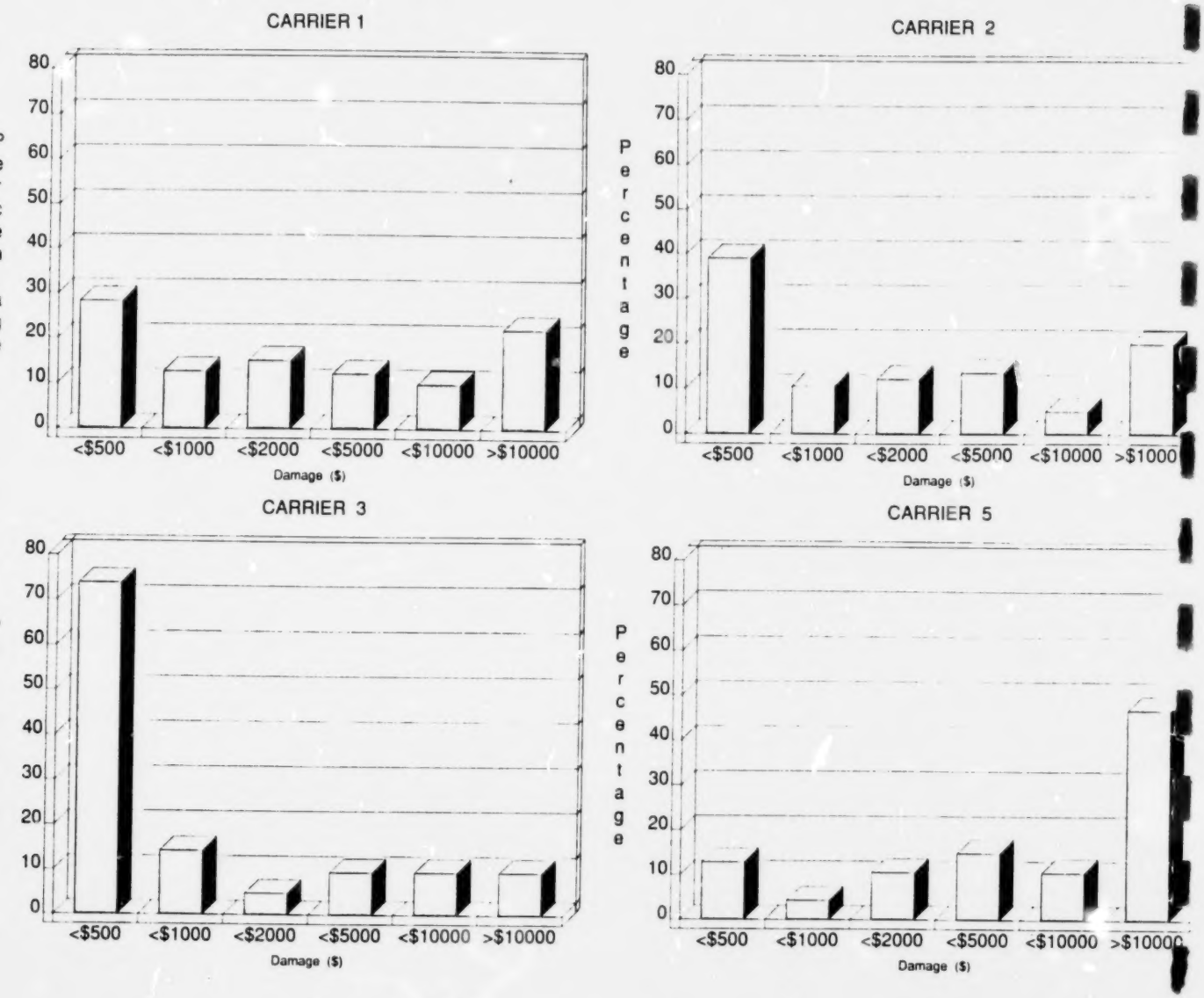
analysis. On the other hand, if there were any possibility of a third party claim independent of the amount of damages, the incident would have been reported to the insurance company and a file would have been prepared. As a result of this constraint, the definition of an accident for carrier 5 is somewhat "fuzzy".

A prerequisite to a meaningful comparison of accident rates is a common definition of an accident. The distribution of fleet specific accident experience relative to severity as measured by accident cost is therefore of obvious interest. This type of information was available for carriers 1, 2, 3 and 5 and is illustrated in Figure 4.2. As the definition of an accident for carrier 5 is different than that for the other carriers, a direct comparison is inappropriate. It is noted that between 28% - 72% of all accidents for carriers 1, 2, and 3 involved costs of less than $500.

### 4.2.2 Standard of Roads

The issue of absolute and relative accident experience is further complicated by the fact that the accident statistics for all fleets include all accidents in rural areas. That is, accidents on both provincial highways and rural roads are included. Accidents within urban areas or yards, at docks, etc. are excluded from the data prior to analysis.

FIGURE 4.2
DISTRIBUTION OF ACCIDENT COST



This inability to segregate rural accidents into those on provincial highways and those on rural roads resulted from the lack of sufficient detail in the description of the location of the accidents in some of the accident files. This detail could have been obtained only with extreme effort through follow-up on an individual accident by accident basis.

It was possible to determine the magnitude of the proportion of total rural accidents associated with provincial highways and rural roads for some of the carriers by combining a review of the information in individual accident files with some judgement. In those cases where an accident occurred on a major highway, the highway number was usually (but not always) included. In some cases the highway number, although not included, was apparent from the description that it was a major highway (i.e. crossed the median). In other cases, it was reasonably clear from the description that the accident occurred on a rural road. There were however a proportion of total accidents for which it was difficult to determine whether the accident occurred on a provincial highway or rural road. This proportion varied from carrier to carrier because of different level of detail in the accident reports.

Using some judgment, the assessment of the relative proportion of total accidents occurring on provincial highways versus rural roads for carriers 1, 2, 3 and 5 is summarized in Table 4.2.

TABLE 4.2

DISTRIBUTION OF ACCIDENTS IN RURAL AREAS

| | CARRIER 1 | CARRIER 2 | CARRIER 3 | CARRIER 5 | AVERAGE |
|---|---|---|---|---|---|
| PROVINCIAL HIGHWAYS | 75.2% | 80.9% | 78.6% | 80.9% | 79% |
| RURAL (Off highway) | 6.4% | 5.7% | 11.9% | 6.4% | 8% |
| UNABLE TO CLASSIFY | 18.3% | 13.5% | 9.5% | 12.8% | 13% |

(Detailed data was not available for carrier 4.) It can be seen that 75% to 80% of all accidents occurred on provincial highways, 5% to 12% on rural roads, and 10% to 19% on roads that were not classified.

Knowing the proportion of rural accidents that occur on provincial highways relative to rural roads is helpful but to be truly useful in terms of determining and analyzing accident rates, the split in total rural travel in terms of the proportion on provincial highways and proportion on rural roads is also required. This detail was not available from any of the five carriers.

It is, however, possible to gain some insight by making some (reasonable) assumptions. For example, if the accident rate for articulated trucks on rural roads is on average twice that on provincial highways (see Table 3.11) and 8% of a carrier's rural accidents are on rural roads, then one would conclude that approximately 4% of the carrier's total rural travel is on rural roads.

It is important to recognize that the relative proportion of rural travel that is on provincial highways and rural roads is also a function of the carrier operations. A carrier heavily involved in the petroleum haul would have a high proportion of total rural travel on provincial highways (i.e. most fuel goes to

cities and towns) relative to a carrier heavily involved in the grain or fertilizer haul (i.e. farm associated). These carrier specific differences in "mix" of travel on provincial highways versus rural roads would be expected to have some effect on overall accident rates for various carriers because, as noted, accident rates on rural roads (in Saskatchewan) are about twice that on provincial highways (in Saskatchewan - see Table 3.11).

### 4.2.3 Operating Region

The five fleets for which accident data was assembled all are based in western Canada and all operate in Saskatchewan. They also operate in other provinces and some operate into the USA. As a result of these different operating areas, the "mix" of operating environments varies substantially from one carrier to the next.

For example, one carrier operates throughout the prairies and British Columbia whereas another operates nearly exclusively in the southern portions of Alberta and Saskatchewan. Another has a heavy proportion of its operation in northern resource areas. These differences create significantly different environments in terms of weather (i.e. snow and therefore visibility), road conditions (i.e. snow pack and ice), and road standard (i.e. grades, curves, paved and gravel) and would therefore be expected to result in different accident experience.

Traffic volumes also tend to vary on a regional basis. That is, traffic levels in Alberta tend to be higher in general than in Saskatchewan. As a result, there is more "third party exposure" in the Alberta region compared to Saskatchewan. As a result, the accident experience on a regional basis would be expected to vary because of differences in general traffic levels.

### 4.2.4 Vehicle Type

Truck body type (tanker, hopper, van, bulker, flat deck etc.) would be expected to have some effect upon accident experience. Since the five fleets studied have quite different "mixes" of vehicle types within their respective fleets, variations in accident experience between fleets is expected. Unfortunately it was not possible to determine accident rates by vehicle type because of the lack of available data.

### 4.2.5 Summary

Accident rates are a function of a (large) number of diverse variables, some of which include:

1) definition of an accident
2) standard of road
3) operating region
4) truck body type
5) other.

Since the "mix" of these variables varies from one carrier to the next, as well as from one time period to the next for a particular carrier, carrier specific accident rates would be expected to vary between carriers and between time periods.

The situation is further complicated by the fact that vehicle accidents are probabilistic in nature (i.e. random). Therefore stochastic variation attributable to the probabilistic nature of vehicle accidents are superimposed upon the expected deterministic variations associated with changing circumstances. This results in a very complex situation if any attempt is made to explain observed differences in accident experience.

A review of Figure 4.1 illustrates that indeed accident rates for particular carriers do vary over time, as well as from carrier to carrier. While temporal variations for some carriers appear relatively small (i.e. about 20% for carrier 1 and 2), these variations can be relatively large (i.e. factor of two) for other carriers (i.e. carriers 3 and 5).

Large changes in accident rates over time are often attributable to deterministic changes in circumstances. For example, there was a change in management for carrier 3 at the end of 1984. As a result, there was a dramatic shift in operating procedures and attitudes toward safety, maintenance, etc. In the case of carrier 5, there was a change in the definition of an accident as

noted earlier (i.e. change in deductible from $2000 to $5000).

In spite of all of these complicating factors, comparisons can be made for the purpose of formulation and implementation of highway safety policies and programs. In this context, fleet specific accident rates for the carriers studied are in the order of 1 - 1.5 accidents per million vehicle km of travel. These accident rates are somewhat higher than those determined for articulated trucks on Saskatchewan provincial highways as summarized in Chapter 3 (i.e. 0.7 - 0.8). In addition to all the other complicating factors (area of operation, truck body type, different definitions of accidents, etc.), the major difference between the accident rates for the five carriers and those reported in Chapter 3 is that the fleet specific data included all accidents in rural areas (i.e. provincial Highways and rural roads) involving any damage or injury (i.e. no deductible except for carrier 5 where the definition of an accident is somewhat "fuzzy".

While a comparison with all things equal is impossible because of the lack of comparable data, it is possible to make a crude comparison by making adjustments for differences where availability of data permits.

These adjustments might be as follows:

| | |
|---|---|
| Fleet Specific Rural Area Accident Rate | 1 - 1.5 accidents per million vehicle km |
| Distribution of Accidents by Severity (average for carriers 1,2 and 3 - see Figure 4.2) | |
| < $500 damages | 45% |
| > $500 damages | 55% |
| Proportion of Accidents | |
| on provincial highways | 79% |
| on rural roads | 8% |
| unable to classify | 13% |
| Proportion of Total Travel | |
| on provincial highways | 96% |
| on rural roads | 4% |

$$\text{Fleet Specific Provincial Highway Accident Rate} = \frac{\text{Fleet specific Rural Area Accident Rate} \times \text{\% of Total Acc >\$500 in Damages} \times \text{\% of Total Accidents on Prov. Highways}}{\text{\% of Total Rural Travel on Provincial Highways}}$$

$$= \frac{1.25 \times 55\% \times 90\%}{96\%} = .64$$

[1]

It is important to note that adjustments have not been made for all variables in the above, but rather only for those that data availability permitted (i.e. there was no adjustment made for region of operation, mix in truck type - tanker, van, etc.). Further, while the adjustments made are at least intuitively

---

1. The 13% that were unable to be classified were proportioned between highways and rural roads in the same proportion as the ones that could be classified (i.e. % Total Accidents on Highways equals 79% + (13 x 79)/(8 + 79) = 90%

appealing, it must be recognized that the reliability is constrained by the quality of data available and therefore must be viewed as an order of magnitude analysis at best.

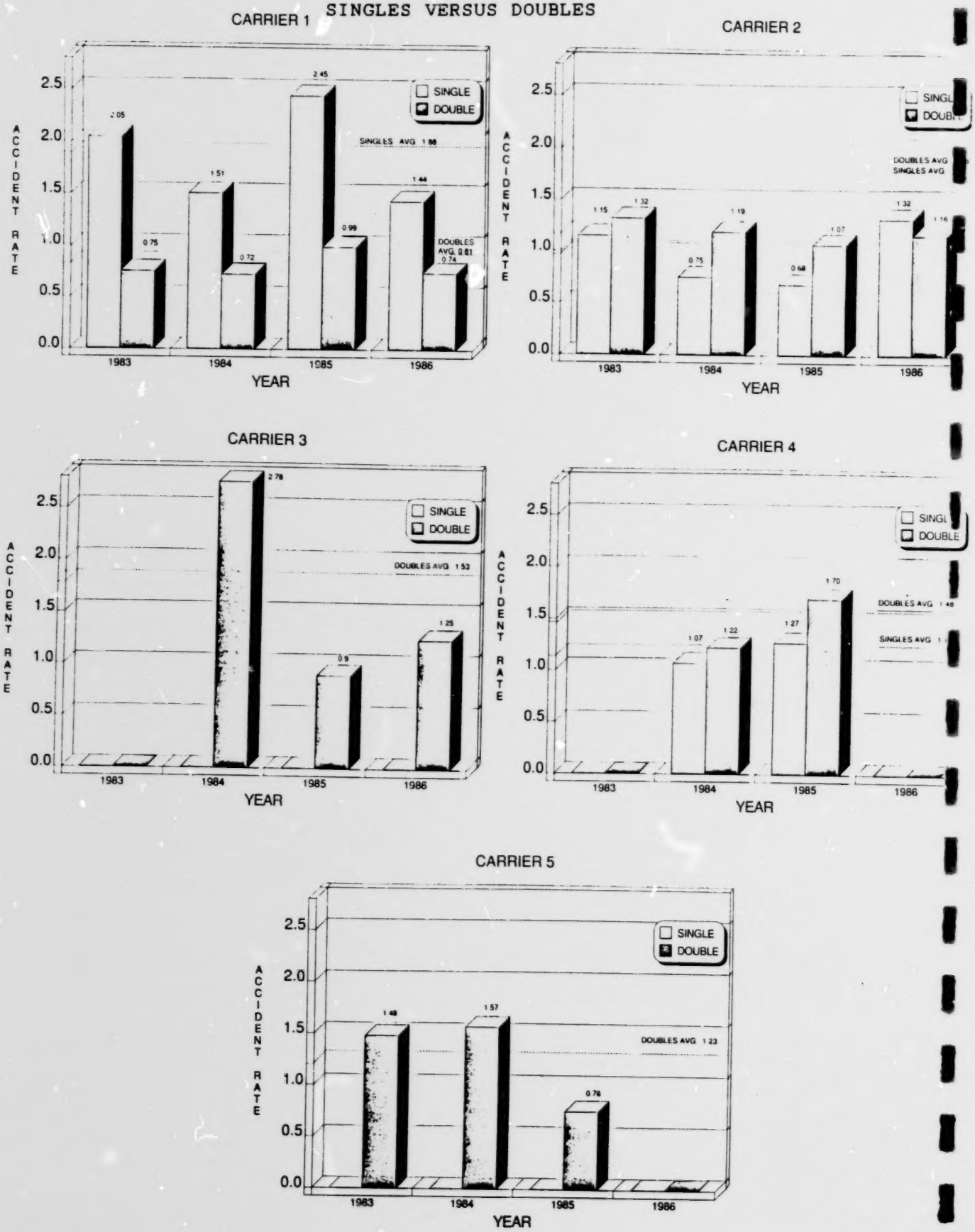
It is important to note that adjustments have not been made for all variables in the above, but rather only for those that data availability permitted (i.e. there was no adjustment made for region of operation, mix in truck type - tanker, van, etc.). Further, while the adjustments made are at least intuitively appealing, it must be recognized that the reliability is constrained by the quality of data available and therefore must be viewed as an order of magnitude analysis at best.

Recognizing the above, the adjusted fleet specific provincial highway accident rates were found to be in the order of 0.64 accidents per million vehicle km and therefore compared reasonably well with the rates determined for all vehicles and articulated trucks on provincial highways in Saskatchewan.

## 4.3 Single Trailers versus Double Trailers

Table 4.1 and Figure 4.3 show the accident experience of the five carriers by year for single and double trailer units. These are for all rural accidents with any damages except for carrier 5 (see section 4.2.1).

FIGURE 4.3
ACCIDENT RATE FOR
SINGLES VERSUS DOUBLES

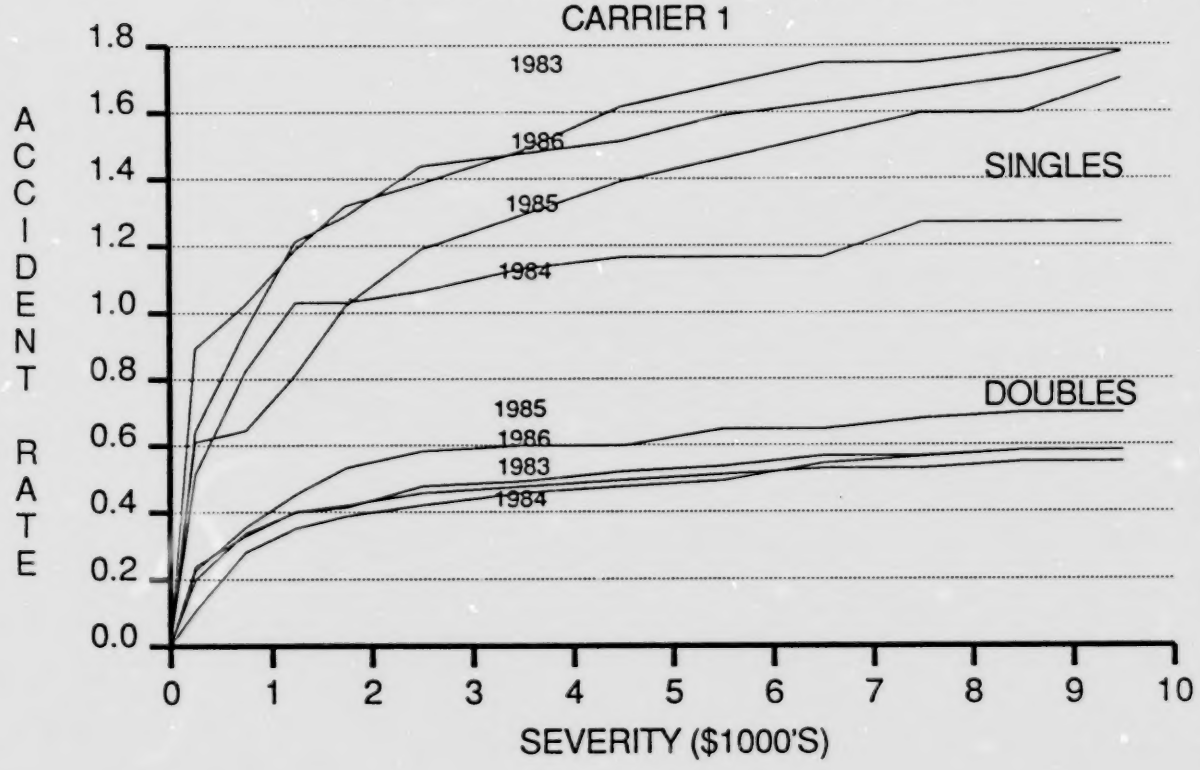


In the case of carrier 1, the accident rate for single trailers appears to be substantially higher than that for doubles (i.e. average over 1983-86 for singles equals 1.88 accidents per million vehicle km relative to doubles at 0.81). On the other hand the experience of carriers 2 and 4 suggest that the accident rate for doubles may be marginally higher than that for singles (i.e. carrier 2 - doubles 1.18, singles 0.98; carrier 4 - doubles 1.48, singles 1.16).

Discussions with officials from carrier 1 indicated that the two types of vehicles are used in substantially different hauls. Single trailer units tend to travel more on secondary highways, rural roads, and resource development roads. Doubles travel more on major highways of high design standard (i.e. shoulders, divided, etc.). It was also noted that the doubles tended to be newer equipment operated by more experienced drivers relative to singles.

In order to compare more fully the accident experience of single versus double trailer units operated by carrier 1, the distribution of the cumulative accident rate versus severity (as measured by costs of damages) was plotted as illustrated in Figure 4.4. These plots confirm that there is a difference in accident experience between singles and doubles in this particular operation. Given the difference in operating environments, maybe these differences should not be all that

FIGURE 4.4
CUMULATIVE ACCIDENT RATE VS SEVERITY
CARRIER 1



surprising.

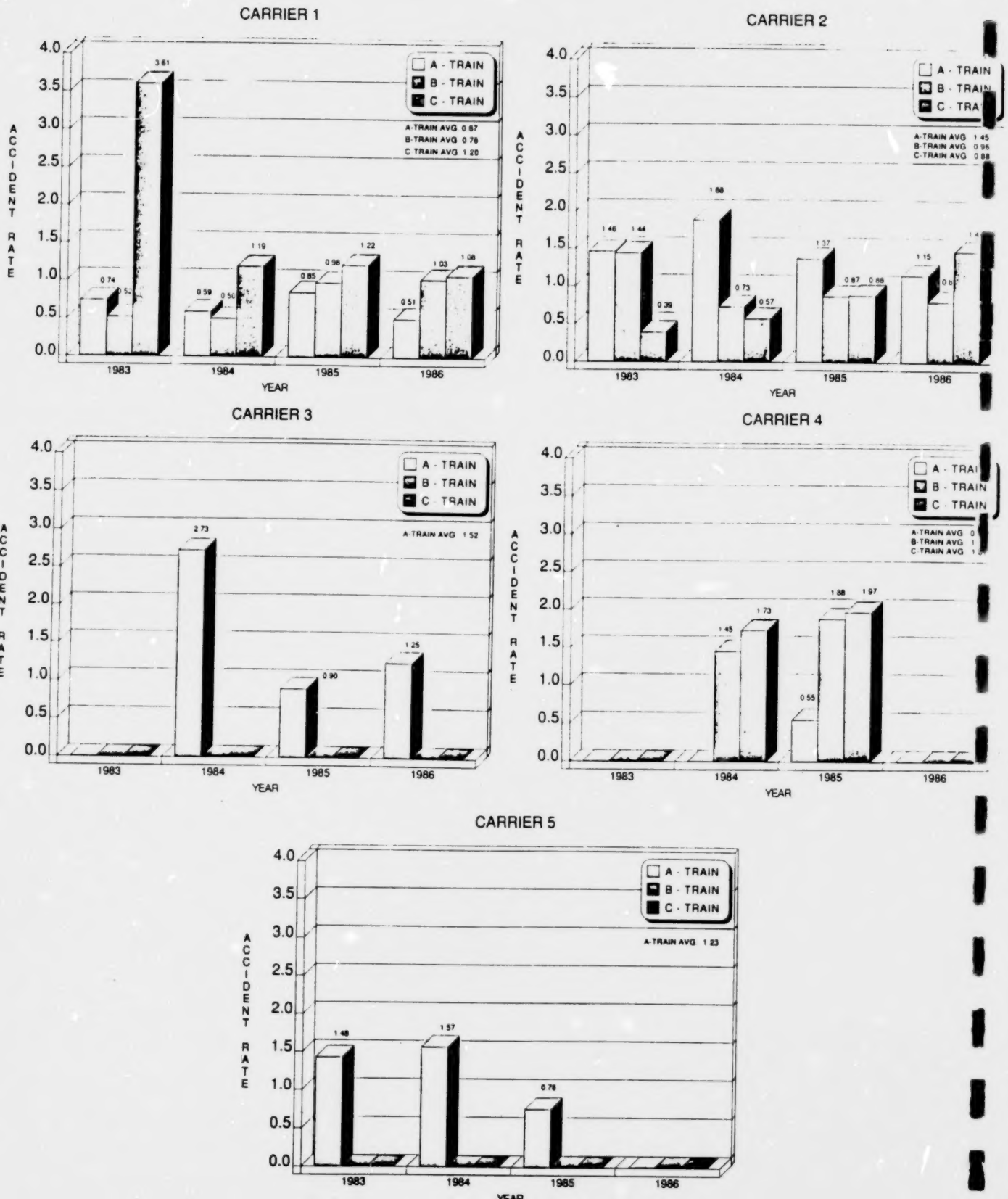
From the above there is some evidence that suggests that the accident experience of singles and doubles can be different. The evidence, however, is not consistent in that doubles appear best in one case, whereas singles appear best in other cases. Intuitively it might have been expected that doubles would have a higher accident rate than singles. This may be true if all other things are equal. However in this case, other determinants (i.e. road type etc.) appear to dominate relative to the issue of vehicle type (i.e. singles versus doubles), in particular for carrier 1 where there are substantial differences and doubles are better than singles.

## 4.4 A Versus B Versus C-Trains by Fleet

Table 4.1 and Figure 4.5 show the accident rates for various configurations by fleet operator by year. These accident rates again include all rural accidents involving any damage except for carrier 5.

Again the statistics illustrate considerable temporal variability for individual configurations operated by specific fleets. There is also considerable variability between carriers for a particular configuration as well as between configurations for a particular carrier. There does not appear to be a particular

FIGURE 4.5
ACCIDENT RATES
BY VEHICLE CONFIGURATION



configuration which consistently dominates in terms of safety experience.

Carrier 1 has had a positive and consistent experience with A-Trains. The experience with B-Trains appears comparable to A-Trains. But, there appears to have been a problem with C-Trains in 1983.

In the case of carrier 2, experience with C-Trains appears to be better than with A-Trains and experience with B and C-Trains appears comparable over the period.

For carrier 4, A-Trains appear to have performed better than B and C-Trains, but B and C-Trains appear comparable.

## 4.5 Summary

The overall experience of the five fleets is summarized in Table 4.3 and illustrated in Figure 4.6.

The overall accident rates of these fleets, when adjusted for differences in circumstance appear comparable to accident rates for all vehicles and articulated trucks operating on Saskatchewan provincial highways.

TABLE 4.3
SUMMARY OF OVERALL EXPERIENCE OF FIVE FLEETS

| DESCRIPTION | FLEET | SINGLES | DOUBLES | A-TRAIN | B-TRAIN | C-TRAIN |
|---|---|---|---|---|---|---|
| TOTAL ACCIDENTS | 718 (1) | 260 (7) | 413 (13) | 236 (19) | 111 (26) | 47 (32) |
| TOTAL TRAVEL (million vehicle kilometers) | 586.3 (2) | 157.3 (8) | 410.3 (14) | 242.9 (20) | 130.1 (27) | 37.9 (33) |
| TOTAL INJURY ACCIDENTS | 85 (3) | 32 (9) | 51 (15) | 34 (21) | 10 (28) | 7 (34) |
| TOTAL FATAL ACCIDENTS | 15 (3) | 7 (9) | 8 (15) | 6 (22) | 0 | 2 (35) |
| OVERALL ACCIDENT RATE | 1.22 (4) | 1.65 (10) | 1.01 (16) | 0.97 (23) | 0.85 (29) | 1.24 (36) |
| INJURY ACCIDENTS PER MILLION km | 0.172 (5) | 0.226 (11) | 0.145 (17) | 0.169 (24) | 0.010 (30) | 0.035 (37) |
| FATAL ACCIDENTS PER MILLION km | 0.030 (6) | 0.049 (12) | 0.023 (18) | 0.030 (25) | 0.0 (31) | 0.071 (38) |

NOTES:
(1) INCLUDES BOB TAILS, 1983-86 FOR CARRIER 1 AND 2, 1984-86 FOR CARRIER 3, 1983-85 FOR CARRIER 4 AND 5
(2) TOTAL TRAVEL FOR ALL 5 CARRIERS, 1983-86 FOR CARRIER 1 AND 2, 1984-86 FOR CARRIER 3 AND 1983-85 FOR CARRIER 4 AND 5
(3) CARRIERS 1,2,3 ONLY, TOTAL TRAVEL 494.4 MILLION VEH. KM.; TOTAL FLEET INJURY ACCIDENTS INCLUDE 2 BOBTAIL ACCIDENTS.
(4) 718 ACCIDENTS IN 586.2 MILLION VEH. KM.
(5) 85 INJURY ACCIDENTS IN 494.4 MILLION VEH. KM.
(6) 15 FATAL ACCIDENTS IN 494.4 MILLION VEH. KM.
(7) ONLY CARRIERS 1,2,4 OPERATED SINGLES, 1983-86 FOR CARRIER 1 AND 2 AND 1984-85 FOR CARRIER 4, EXCLUDES BOBTAILS.
(8) 1983-86 FOR CARRIER 1 AND 2, 1984-85 FOR CARRIER 4, TOTAL TRAVEL 157.3 MILLION VEH. KM.
(9) 1983-86 FOR CARRIER 1 AND 2 ONLY, TOTAL TRAVEL 141.8 MILLION VEH. KM.
(10) 260 ACCIDENTS, 1983-86 FOR CARRIER 1 AND 2, 1984-85 FOR CARRIER 4, TOTAL TRAVEL 157.3 MILLION VEH. KM.
(11) 32 INJURY ACCIDENTS, 1983-86 FOR CARRIER 1 AND 2, TOTAL TRAVEL 141.8 MILLION VEH. KM.
(12) 7 FATAL ACCIDENTS, 1983-86 FOR CARRIER 1 AND 2, TOTAL TRAVEL 141.8 MILLION VEH. KM.
(13) ALL CARRIERS OPERATED DOUBLES, 1983-86 CARRIER 1 AND 2, 1984-86 CARRIER 3, 1983-85 CARRIER 4 AND 5, 413 TOTAL ACCIDENTS
(14) 1983-86 CARRIER 1 AND 2, 1984-86 CARRIER 3, 1983-85 CARRIER 4 AND 5 FOR A TOTAL TRAVEL OF 410.26 MILLION VEH. KM.
(15) 1983-86 CARRIER 1 AND 2, 1984-86 CARRIER 3, TOTAL OF 51 INJURY ACCIDENTS
(16) 413 ACCIDENTS IN 410.29 MILLION VEH. KM. ON TRAVEL
(17) 51 INJURY ACCIDENTS IN 352.6 MILLION VEH. KM. OF TRAVEL
(18) 8 FATAL ACCIDENTS IN 352.6 MILLION VEH. KM. OF TRAVEL
(19) ALL CARRIERS OPERATED A-TRAINS, 1983-86 FOR CARRIER 1 AND 2, 1984-86 FOR CARRIER 3, 1984-85 FOR CARRIER 4, 1983-85 FOR CARRIER 5, TOTAL OF 236 ACCIDENTS
(20) TOTAL A-TRAIN TRAVEL 242.9 MILLION VEH. KM., SAME PERIOD AS IN NOTE 19
(21) 1983-86 FOR CARRIER 1 AND 2, 1984-86 FOR CARRIER 3, TOTAL OF 34 INJURY ACCIDENTS
(22) SAME CARRIERS AND PERIODS AS NOTE 21: TOTAL OF 6 FATAL ACCIDENTS
(23) 236 ACCIDENTS IS 242.9 MILLION VEH. KM.
(24) 34 INJURY ACCIDENTS IN 200.82 MILLION VEH. KM.
(25) 6 FATAL ACCIDENTS IN 200.82 MILLION VEH. KM.
(26) ONLY CARRIERS 1,2 AND 4 OPERATED B-TRAINS, 1983-86 FOR CARRIER 1 AND 2, 1984-85 CARRIER 4, TOTAL OF 111 ACCIDENTS
(27) TOTAL B-TRAIN TRAVEL 130.1 MILLION VEH. KM., SAME PERIOD AS IN NOTE 26
(28) 1983-86 FOR CARRIER 1 AND 2, TOTAL OF 10 INJURY ACCIDENTS
(29) 111 ACCIDENTS IN 130.1 MILLION VEH. KM.
(30) 10 INJURY ACCIDENTS IN 101 MILLION VEH. KM.
(31) NO FATAL ACCIDENTS
(32) ONLY CARRIERS 1,2 AND 4 OPERATED C-TRAINS, 1983-86 FOR CARRIER 1 AND 2, 1984-85 CARRIER 4, TOTAL OF 47 ACCIDENTS
(33) TOTAL C-TRAINS TRAVEL 37.93 MILLION VEH. KM., SAME TIME PERIOD AS NOTE 32
(34) 1983-86 CARRIER 1 AND 2, TOTAL OF 7 INJURY ACCIDENTS
(35) 1983-86 CARRIER 1 AND 2, TOTAL OF 2 FATAL ACCIDENTS
(36) 47 ACCIDENTS IN 37.93 MILLION VEH. KM.
(37) 7 INJURY ACCIDENTS IN 28.32 MILLION VEH. KM.
(38) 2 FATAL ACCIDENTS IN 28.32 MILLION VEH. KM.

FIGURE 4.6
OVERALL ACCIDENT EXPERIENCE OF 5 FLEETS

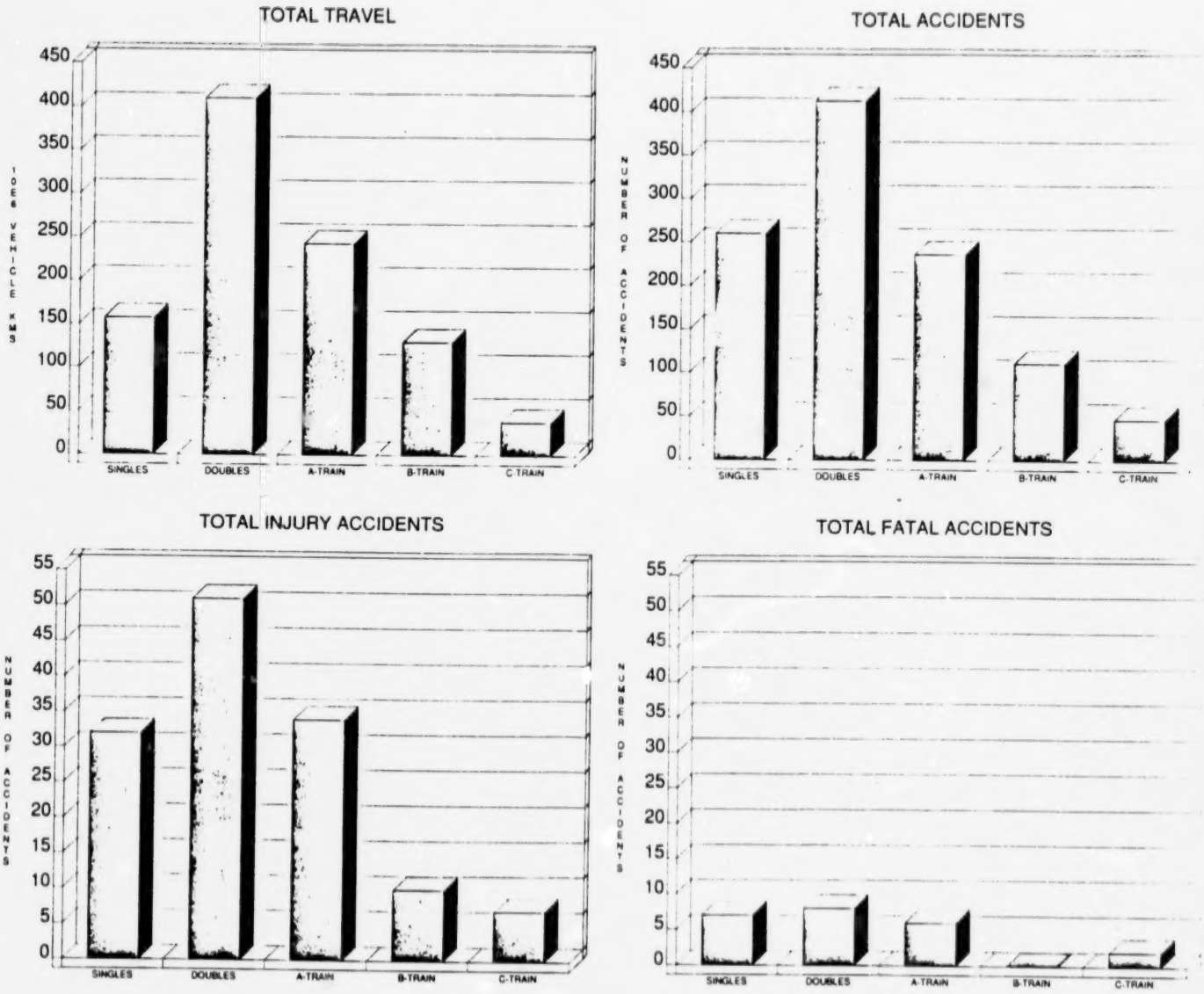
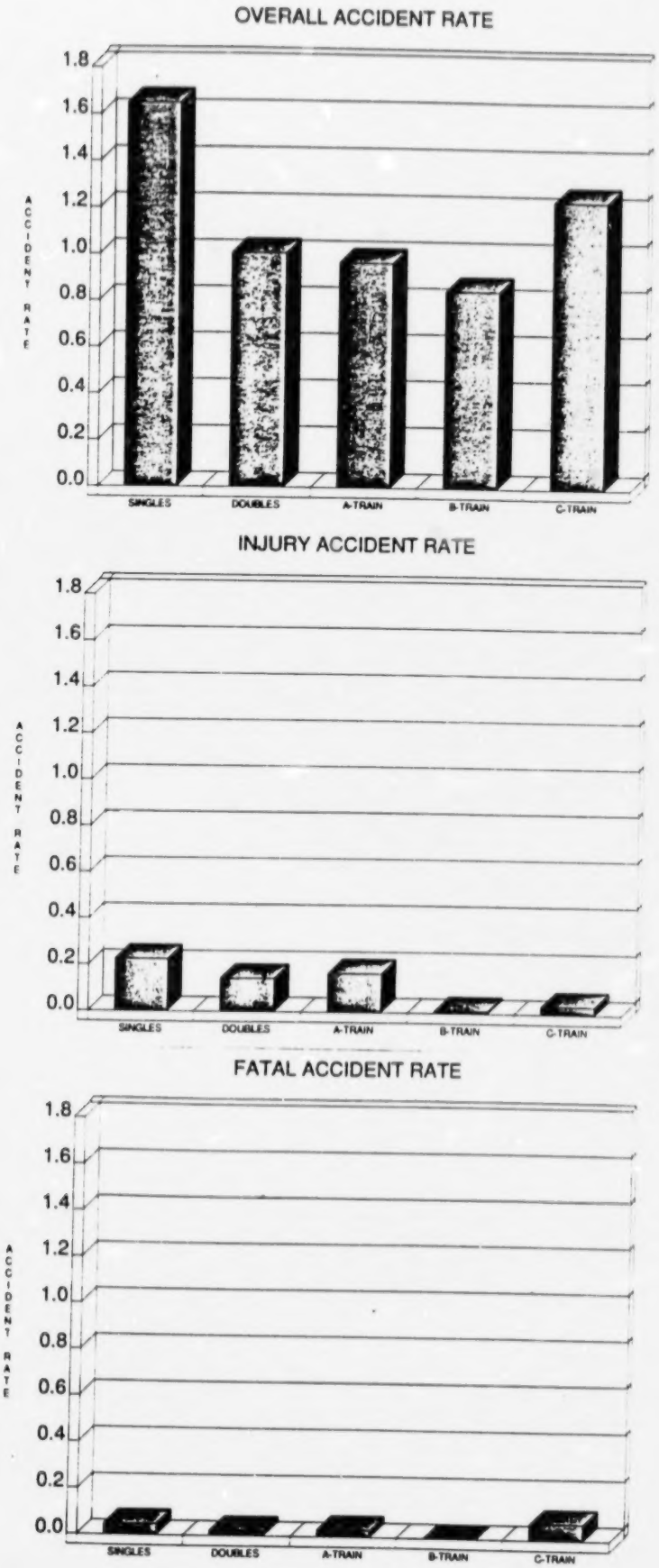


FIGURE 4.6
(CONTINUED)



With the exception of carrier 1, there were no obviously consistent differences in accident rates of singles versus doubles. In the case of carrier 1, doubles appeared to perform substantially better than singles. This is probably attributable to different operating environments (i.e. road type) and possible age of equipment and driver experience.

The substantial difference in the performance of singles versus doubles for carrier 1 is reflected in the summary of fleets presented in Table 4.3 and Figure 4.6, where doubles appear to have a better overall performance than singles across the fleets (i.e. 1.01 versus 1.65 accidents per million vehicle km).

In terms of the performance of A, B, C-Trains, there were no obvious and consistent difference observed, except for some problem with C-Trains experienced by carrier 1 in 1983 and A-Trains by carrier 3 in 1984. The accident rates for carrier 4 for B and C-Trains appear somewhat higher relative to the experience of the other carriers.

Implicit in the above was the expectation that singles would be observed to perform better than doubles and B and C-Trains would be found to perform better than A-Trains. In this sense, the findings are at best inconclusive and potentially counter-intuitive in some cases.

The important point illustrated by the analysis is the fact that a simplistic approach is obviously inappropriate. That is, there are a large number of important variables involved in determining accident experience generally and for articulated trucks in particular. The issue of single trailers versus double trailers and A versus B versus C-Train configurations are just some of the many variables. In fact the evidence presented here suggests that single versus double or A versus B versus C-Train configurations may not be nearly as important as other variables such as road standards and operating regions.

Safety experience cannot be equated to single versus double or A versus B versus C-Trains as was done at least implicitly in the early sections of this report. These parameters may only play a minor role relative to others in terms of overall accident experience of articulated trucks.

To pursue this point, the details of the accidents for carriers 1, 2, and 3 were reviewed in an attempt to determine how important the issue of single versus double or A versus B versus C-Train configurations was in terms of the overall accident experience of articulated trucks. This (subjective) analysis indicates that only 35% of truck accidents have anything to do with vehicle stability (i.e. single versus doubles, A versus B versus C-Trains). That is, the majority of articulated truck accidents involve nonstability related factors only (i.e. hit a

deer, third party ran into the back of the truck etc.).

Further, of the accidents in which stability could play a part, it is not always obvious that doubles are always worse than singles or that any particular configuration is always better.

To illustrate, one operator indicated that A-Train pups are maybe less stable than the C-Train configuration but if the wheels of the unit are dropped over the shoulder of the road (which is a common cause of truck accidents in Saskatchewan) a more serious accident is likely to result with a C-Train than an A-Train. This is because in these circumstances the pup on the A-Train may flip but seldom would the whole unit roll. On the other hand, the chances of rolling the whole unit are higher for a C-Train configuration.

The fact that only a small portion of all truck accidents are in any way related to single versus double or A versus B versus C-Train configurations does have potentially important implications to this study. This is because the truck accident data involved all accidents. The intent here was to focus on the differences associated with single versus double or A versus B versus C-Train configurations. As a result the accident data contained considerable "noise" associated with parameters other than those of specific interest herein. This "noise" may have negated the possibility of observing differences that do exist. This issue

is pursued in the next section by using statistical testing techniques.

# Chapter 5: Statistical Analysis of Large Truck Accident Risk

## 5.1 Introduction

The previous chapter discussed the fleet-specific data on large truck accidents. Qualitatively, there appear to be differences in the risks associated with single versus double-articulated trucks, in particular for carrier 1, but the differences if such exist among the different train types are less obvious. Another characteristic of the data is that it appears as though the accident experiences are quite different from fleet to fleet. This is potentially an important fact because it means that a conclusive analysis would account for different mixes in road type, operating areas, vehicle type (tanker, van, etc.), driver experience etc. related to each carrier as well as the truck types involved (i.e. single versus double or A versus B versus C-Train).

This chapter applies formal statistical analysis to the fleet data to support the qualitative findings of the previous chapter. However, it must be emphasized that the feasible statistical tests are weak. There is a substantial possibility that differences, (albeit small, i.e. < 20%), do exist among the train types, but that they cannot be detected with statistical significance given the existing sample of data. Reasons for this are the inter-carrier differences, the lack of data on other causative variables, and the paucity of observations in the current sample.

Before presenting analysis results, some of the concepts used for statistical inference will be introduced to help explain the selection of statistical techniques. This discussion will also help qualify and clarify the interpretation of the statistical findings.

## 5.2 The Concept of Statistical Significance

Statistical tests are methods for determining whether to accept a hypothesis based on a sample of data. The criterion for accepting a hypothesis is that the risk of declaring an effect to exist where there is actually none is kept below some arbitrarily selected probability. This risk is described by the "confidence level". For instance, if a difference between two accident rates is significant at the 95 percent confidence level, then there is only a 5 percent risk that such a large difference would have been observed when in fact there is no actual difference.

The confidence level does not refer to the probability that we might not find a significant difference even though there really is a true difference. As will be shown below, this second type of risk may be quite large, and gets larger as one increases the confidence level required to label an observed effect as statistically significant. For a given required confidence level, the second type of risk (of false rejection) becomes large when

the effect being tested is small or when the number of observations in the sample is small, both of which are present in the fleet specific large truck accident database.

The standard procedure is to require high confidence levels (e.g. greater than 90 percent) before declaring an effect to be significant. This is based on the premise that it is better to fail to recognize real effects than it is to falsely declare an effect to exist. Thus if a result is "statistically significant", then there is a very small probability that the observed difference is not evidence of a real difference. However, if a result is not found to be statistically significant, there may still be a good chance that an actual difference does in fact exist. As the last part of this chapter will show, a 95 percent confidence level requirement leaves only about a 1 in 4 chance of being able to identify a real difference in A and C-train stabilities with significance, given the current data.

## 5.3 Methods of Testing for Significant Effects

Numerous statistical procedures are available for identifying significant differences. It is important to select the procedures that are best matched to the problem. Before presenting the results, the methods used herein will be described and the choice will be explained.

Ideally, a test for the effect of vehicle type (single versus double) or vehicle configuration (A versus B versus C-Train) on accident risks would involve multivariate analysis, which allows many different variables to each explain their respective part in the causes of accidents. Examples of multivariate analysis that could be applied to accident analysis are regression analysis, and discrete event analysis such as logit, probit or tobit analysis. The vehicle type and vehicle configuration could be two such explanatory variables, but any effect ascribed to it by a multivariate analysis would be only that part not somehow also associated with any of the other explanatory variables, which could include road type (i.e. provincial highway versus rural road), operating environment (i.e. prairies versus mountain), vehicle type (i.e. tanker, hopper, van etc.), or other vehicle, driver, road or environmental characteristics.

The reason multivariate tests would be the most appropriate, if the data were available, is that there are many causes of truck accidents other than truck type and configuration, and these other variables may be correlated in part with the type and configuration of truck being used. If these other controlling variables are not included in the analysis, then any difference observed in accident rates among different truck types or configurations may not be directly attributable to the truck type or configuration per se. It will be attributable to all causes that are in any way correlated with the truck type and

configuration.

For instance, assume that single and double-articulated trucks are equally safe if driven under the exact same circumstances. If however, single trucks are mostly driven on two-lane highways, and double trucks mostly on safer divided highways, then a higher level of accidents will be observed for single trucks, and the difference may well be significant. However, the statistical test cannot indicate whether that significant difference is due to the truck type or to the road type, or to a combination of both. If road type was added as another variable in the analysis, simultaneously with truck type, then the test would be able to determine to what degree the difference can be attributed to each cause.

As long as any of the causative variables are missing from the test, the effect attributable to the truck type could be biased, and possibly falsely significant. This false significance cannot be avoided except by careful selection of the variables that are to be included in the multivariate analysis. However, none of the multivariate analysis options are feasible with the current dataset. To predict accident risks in this way would require data on a truck-by-truck basis, preferably including those trucks that never did get into any accident. Also, the currently available explanatory variables are very limited.

Since truck-by-truck data are not available, then we must turn to the available univariate tests for comparison of accident rates and raw numbers of accidents. In doing so, it is important to remember that any significant effects found may be due to some cause not related to the inherent stability performance of the truck types or configurations (i.e. single versus double, A versus B versus C-Trains). Further, actual performance differences due to truck type alone may be buried or reversed by these other causes of accidents.

There are two univariate tests that are particularly useful in this setting. The first test is a comparison of the average accident rates for each truck type. This test uses the fact that the average (or "mean") of a sample will be normally distributed, since each sample is just one of many possible samples taken from the universe of accidents.[*] It can then be shown that the difference of two sample means is also normally distributed with mean equal to the observed differences and standard deviation equal to the square root of the two sample variances divided by the number of observations in each sample.

That is, if $\bar{X}_s$ and $\bar{X}_D$ are the sample means for the average number of accidents per million vehicle km of travel by single and double units, and $S_s^2$ and $S_D^2$ are the sample variances and $n_s$ and $n_D$ are the sample sizes, then $\bar{X}_s$ and $\bar{X}_D$ will be normally distributed as follows:

$$\bar{X}_s \text{ is } N\left(\mu_S, \sqrt{\frac{\sigma_S^2}{n}}\right) \qquad \text{and}$$

$$\bar{X}_D \text{ is } N\left(\mu_D, \sqrt{\frac{\sigma_D^2}{n}}\right)$$

Further, $(\bar{X}_s - \bar{X}_D)$ will also be normally distributed as follows:

$$(\bar{X}_s - \bar{X}_D) \text{ is } N\left(\mu_S - \mu_D, \sqrt{\frac{\sigma_S^2 + \sigma_D^2}{n_S + n_D}}\right) .$$

To test the hypothesis that the two means are significantly different from each other involves the use a normal distribution with a standard deviation equal to that calculated according to the formula above. A test related to this is the F-test. This is used to test the hypothesis that more than two normally distributed means are all equal to each other. It is an extension of the difference of means test and so the result of the F-test for only two variables is identical to the normal test of a difference of the two means. The F-test is relevant when comparing the three train types simultaneously. For instance, if the observed difference in means is more than 1.645 standard deviations away from zero, then it can be said that there is 95 percent confidence that one accident rate is significantly higher than the other. The numbers used above come from a standard table for the areas under a normal curve, such as Table F of Parsons, ibid. p.818. The observed differences required for all other confidence levels can also be determined in this way.

The second test that is of use for these data is called the Chi-squared test of independence. This test is useful for comparing data that can be placed into multiple discrete categories, such as the raw numbers of accidents. For instance, each double-articulated truck accident can be categorized by train type and by whether an injury occurred or not. This leads to six discrete categories, exactly one of which fits for each accident in the database. Once all of the accidents have been allocated to a category, the Chi-squared test determines the degree to which the numbers of accidents in each category are different from that which would be expected if the train type did not affect the probability of injury. It is possible to determine the degree of significance in those differences, just as with the normal distribution tests described above.

## 5.4 Outline of the Statistical Analysis Performed

Differences in truck accident risks are analyzed in two ways. First, we compare accident rates (i.e. accidents per million vehicle kilometers). Second, we look at the severity of accidents, once an accident does occur. Severity can be defined as the degree of property damage, injury or fatality observed in each accident. These two types of accident risks are compared along several dimensions:

- o single vs. double-articulated trucks
- o A-Train vs. B-Train vs. C-Train (jointly and pairwise)
- o by carrier type.

In addition, although other causative variables cannot be included, we did try to eliminate some of the accidents that cannot be attributed to differences in truck configuration. This was done by judgmentally reviewing the record for each accident, and constructing a subset database that excludes all accidents that do not appear to have been related to truck stability, such as accidents where the truck was rear-ended by a third party. The smaller database was expected to provide less biased estimates of the stability-related effects of different truck types on accident risks. As will be seen, it appears that the cleaner "stability-related" database does provide a story more consistent with intuition than does the full, "overall" database. The results should not however be considered as good as those of a multivariate analysis because of the judgement needed to determine which accidents are stability-related.

To summarize the results that will be addressed in detail in the remainder of this chapter, the comparison between single and double trailer units indicates differences that are not due to stability, probably attributable to differing usage patterns. For double-articulated trucks alone though, the stability-related data indicate that B-Trains have fewer stability problems than either A

or C-Trains. A and C-Trains do not display significant differences in their stability risks, but there is some evidence that C-Trains may result in more serious accidents than A-Trains. The overall accident risks do not follow the same pattern: there are many other important causes of truck accidents that overwhelm the stability effects in these data. However, the overall data do still indicate that C-Trains may result in the most property damage or injuries. Thus although we obtain some provocative results, it is clear that there are so many factors other than stability that only a multivariate analysis can hope to provide a definitive statistical assessment of the relative risks.

Despite the caveats above, it is still important to reiterate that even if a significant difference has not been detected, a small but real difference in risks may exist. The last part of this chapter will demonstrate that effects as large as a 10 percent increase in accident rates between A and C-Trains are very unlikely to be statistically detectable (with significance) unless many years of additional accident data were available. A 10 percent increase in accident rates translates into about 15 additional accidents per 100 million km driven. In the context of Saskatchewan, this 10% difference would translate into about 15 more accidents per year. (Total articulated truck travel equals about 500 million vehicle km per year, assume 50% by singles and 50% by doubles with 1/3 of the double unit travel by each A, B, and C-Train configurations; therefore the total travel by say A-

Trains would be about 100 million vehicle km per year.)

In the specific findings below, any result with a significance level below 85 percent is considered insignificant. The confidence level of all significant results is provided. The details related to the statistical tests are included in the Appendix.

## 5.5 Risks of Single Versus Double Articulated Trucks

Before considering the issues of train type, the accident rate pattern of all double-trailer combinations versus that of single-articulated trucks will be examined. This analysis, based on a difference of means test, indicates that there are significant differences in accident rates, with single trucks being more risky than doubles. This result is largely due to the strong effect found in carrier 1's accident experience. While it remains when looking at the stability-related data, its significance is diminished. More specific results are provided in Table 5.1.

TABLE 5.1

COMPARISON OF SINGLE AND DOUBLE
ARTICULATED TRUCK ACCIDENT RATES
(significance levels are stated in parentheses)

| | All Data | Stability-related Data |
|---|---|---|
| Carrier 1 | S rate 132% worse (1) (99.9%) (2) | S rate 88% worse (96%) |
| Carrier 2 | D rate 22% worse (80%) | D rate 24% worse (48%) |
| Pooled | S rate 89% worse (97%) | S rate 45% worse (91%) |

(1) This means the accident rate for singles is 2.32 times that for doubles.

(2) Percentages of 85% and over are considered to be significant.

Thus we can say that the difference in results between overall data and stability-related data indicates that single-articulated trucks may have the higher accident rate, but that the reason is not strongly related to differences in truck stability. The potential for bias due to missing explanatory variables is very high in this comparison because there are very significant differences in the usage patterns of each of these two types of trucks. Therefore the interpretation of statistical significance cannot be extended to imply an inherent difference in the risks of the two truck types. Possibly it is due to the different usage patterns of single trucks (e.g., on more hazardous roads, or with less skilled drivers). We should also be careful to note that

this observed difference is due to the very significant experiences of carrier 1 only.

Only carriers 1 and 2 are included in the pooling because of the importance of the differences in rates among carriers. Since the other carriers do not have both singles and doubles, then including their rates for only one truck type could unfairly bias the results for or against the other truck type. For example, carrier 3 appears to have higher accident rates than carriers 1 or 2 for double-articulated trucks. If carrier 3 had any single-articulated trucks, then this higher accident rate might also appear in the singles data. Pooling carrier 3's data with the more complete data of carriers 1 and 2 could unfairly bias the comparison to make double-articulated trucks look worse, when in fact the underlying problem might be that carrier 3, who happens to have only double-articulated trucks, also happens to have higher accident rates.

## 5.6 Relative Risks of A, B and C-Trains

The above has established that single-articulated trucks may be more risky than doubles, although probably mostly because of factors not related to the inherent stability of each type. That comparison did not distinguish among the three train types (i.e. A versus B versus C-Trains). It is of interest to determine whether a difference in accident rates can be found among the train types.

This can be done using the F-test and difference of means tests among the three train types.

Briefly, the F-test does not indicate that there are significant differences among all three of the train types. Pairwise comparisons however indicate that B-Trains have significantly fewer accidents per unit of distance travelled than A or C-Trains, apparently due to differing stability characteristics. Further, there does not appear to be any significant difference in the accident rate of A and C-Trains attributable to stability differences.

The first pairwise comparison that we will look at is that between the accident rates of B and C-Trains. Table 5.2 provides specific results that make it clear that C-Trains generally have higher rates than the B-Trains, but that the differences are not clearly significant except when looking at pooled stability-related data. In the last case, we can accept the hypothesis (95% level) that B-Trains are less risky than C-Trains.

TABLE 5.2

COMPARISON OF B-TRAIN AND C-TRAIN ACCIDENT RATES
(significance levels are stated in parentheses)

| | All Data | Stability-related Data |
|---|---|---|
| Carrier 1 | C rate 133% worse (90%) | C rate 102% worse (40%) |
| Carrier 2 | B rate 16% worse (36%) | C rate 80% worse (92%) |
| Pooled | C rate 15% worse (64%) | C rate 133% worse (98%) |

For carrier 1 both the "other" types of accidents and stability-related accidents appear to be worse for C-Trains. It appears that carrier 2 also has C-Train stability problems (relative to B-Trains) but that this fact is masked by a variety of other causes of accidents that affect B-Trains more than C-Trains. In the stability-related data, a completely different picture begins to emerge for carrier 2; one that is consistent with the experience of carrier 1. Thus, the combined experience of carriers 1 and 2 indicates that there may be significant stability problems with C-Trains relative to B-Trains.

If C-Trains have worse stability than B-Trains then how do C-Trains compare to A-Trains? Here it appears that there is not a significant difference in the overall accident rates or the stability-related rates. Table 5.3 summarizes the results, where again the significance level of each result is provided in

parentheses.

TABLE 5.3

COMPARISON OF C-TRAIN AND A-TRAIN ACCIDENT RATES
(significance levels are stated in parentheses)

| | All Data | Stability-related Data |
|---|---|---|
| Carrier 1 | C rate 162% worse (93%) | C rate 6% worse ( 7%) |
| Carrier 2 | A rate 77% worse (98%) | A rate 49% worse (77%) |
| Pooled | C rate 13% worse (56%) | C rate 12% worse (32%) |

When looking at overall rates, carrier 1 and 2 have conflicting results, each of which is significant. (93% and 98% levels respectively). Carrier 1 appears to have more problems with C-Trains and carrier 2 appears to have more problems with A-Trains. When stability-related data is looked at however, the significance of the differences disappears. Thus although there are significant differences for each carrier, the direction of the differences is different, and as would be expected, the differences do not appear to be tied to stability risks.

As a consistency check, do the above results mean that B-Trains are also significantly better than A-Trains? When looking at stability-related data only, the answer is a clear yes, even more

so than for B versus C-Trains. B rates are significantly lower than A rates with 94%, 99.5% and 99.5% significance for carriers 1, 2, and pooled data respectively, as seen in Table 5.4.

TABLE 5.4

COMPARISON OF ACCIDENT RATES FOR A VERSUS B-TRAINS
(significance levels are stated in parentheses)

| | All Data | Stability-related Data |
|---|---|---|
| Carrier 1 | B rate 13% worse (40%) | A rate 91% worse (94%) |
| Carrier 2 | A rate 53% worse (98%) | A rate 169% worse (99.5%) |
| Pooled | A rate 4% worse (21%) | A rate 108% worse (99.5%) |

## 5.7 Inter-Carrier Comparisons

Throughout the above there are the confounding factors of differences among the carriers. A difference of means test to compare the rates for carrier 1 and carrier 2 indicates no significant difference in total rates, but significant differences in the single and double rates alone. When looking at stability related data, carrier 2 has a higher double accident rate than carrier 1. This effect carries over to the total accident rate.

The interpretation of this pattern is that when it comes to accidents related to stability, the differences in the double rate and the difference at the total accident rate level is probably

due to differences in the relative amounts of single and double traffic that the two carriers have. However, when all types of accidents (stability-related and other) are accounted for, then there are quite important differences in the two carriers. This would reflect differences in routes, drivers, or other firm-specific characteristics. Thus we can probably trust results comparing train types obtained from stability-related data more than we can trust overall data results.

We should note that for comparing the accident rates across carriers it is probably better to apply the Chi-square test because we can categorize accidents by carrier as well as by type of truck. This will allow us to determine if the patterns in numbers of accidents in single and double categories is independent of the carrier. This test found extremely significant differences between the patterns for the two carriers (>99.9% level for both stability-related and overall data). The Chi-square test was also applied to test for differences in carriers among A, B and C-Train accident patterns, and found no statistical significance.

To sum up, the differences among carriers may be very important at the overall level, but if data can be reduced to stability-related accidents only, some of this inter-carrier noise may be filtered out. Inter-carrier differences do not seem to be significant when comparing the safety record of different types of double-

articulated trucks.

## 5.8 Differences in Severity of Accidents Among Truck Types

The analysis this far indicates that C-Trains may be no more stable than A-Trains, but that both A and C-Trains may be more prone to accidents than B-Trains due to the stability of each truck configuration. Another issue to investigate is whether there is more danger when a C-Train gets into an accident. To test this hypothesis, Chi-square tests of independence were applied to data on property damage, injuries and fatalities, for accidents with each of the truck types. Again, the analysis was performed for single versus double-articulated trucks, and for the comparison among the three train types.

In this analysis, there may be fewer problems with pooling data since it seems that the potential for damage once an accident occurs would be the same regardless of the carrier, driver or road. A conflicting argument is that different companies may report damages differently, so while caution is needed, we emphasize pooled results below. By pooling data we get larger samples, which is an important factor here.

### 5.8.1 Property Damage

When using the Chi-squared test, one should have at least 5 observations expected in each category. In the pooled stability-related data for train type and for all fatality comparisons, this rule is violated. When the rule is violated, the squaring of differences from expected frequencies will lead to small numbers and will grossly underestimate the importance of deviations. Thus, one should discount all stability-related data and all non-pooled overall data for the train type comparisons. In addition, one should not trust the fatality results even for singles versus doubles. The results are presented here only for completeness.

When looking at stability related data, there is significance in the test that singles are different from doubles, with double-articulated trucks apparently having less property damage in their accidents, but this difference disappears when looking at overall results.

When comparing among train types for the double-articulated trucks only, there are highly significant (94% level) differences, largely due to A and C-trains both being much worse than B-trains. A and C-trains however are not significantly different from each other in the risk of property damage. This difference disappears when we look at stability-related data only. We surmise that this is due more to small samples than to any structural effect. If

sample size is the cause, then the risk of property damage in accidents with A and C-Train trucks may be significantly larger than with B-Train accidents.

5.8.2 Injuries (see paragraph 1, section 5.8.1)

Stability-related data indicate a strong (97% level) difference in risk of injuries occurring between single and double-articulated truck accidents, but this disappears when looking at the overall accident data. Apparently accidents that involve controllability of the truck also involve greater risks of injury if the truck is double-articulated.

When comparing risks of injury in accidents with different types of truck trains, it appears that there is a significant difference in the overall data (87% level). Further, this is due to C-Trains being worse than A or B-Trains. This disappears in the stability-related data, probably because of small sample sizes.

5.8.3 Fatalities (see paragraph 1, section 5.8.1)

The same pattern among train types emerges for risks of fatalities in an accident: A and C are about equivalent, but both are substantially worse than B-Trains. The trend again disappears in stability-related data, because of apparent sample size problems.

In summary, there appears to be recurrent evidence that A and C-Trains create worse types of accidents than do B-Train trucks. Further, some evidence supports an argument that C-Trains may be worse than A-Trains in terms of the likelihood of injuries. Small sample sizes create difficulties in fully interpreting the results.

## 5.9 Sample Sizes Necessary to Detect Effects With Significance

In the above we have been unable to find concrete evidence that A Trains are more likely than C-Trains to get into accidents due to their presumed greater instability. We have also noted that it is possible that C-Trains are worse than A-Trains, but that the small sample size of four years is a problem in identifying this fact. It is interesting to ask how much more data would be necessary to be able to identify an actual effect if it does exist. The answer is that this depends on the magnitude of the actual difference between the two, and also on how high a level of confidence is required to avoid accepting an observed difference as significant when there is in fact no difference at all.

If we look at a variety of scenarios suggested by the data, we find that there is less than a 30 percent chance of being able to detect an effect with 95 percent confidence when the actual difference is in the range of 20-30% and there are only 4 years in the dataset. Further, by adding another 4 years to the dataset,

the probability of finding an effect of this actual size is still less than 50 percent. Most importantly, it appears that the power of the test is greatest when looking at stability-related data. This is because the differences due to stability may be larger relative to the means, even though the mean accident rates themselves will of course be lower.

Tables 5.5 and 5.6 provide more detailed results from which we have summarized to obtain the above statements. The tables are based on assumptions that the mean accident rate for A-Trains is equal to that observed in the pooled data, and that the mean accident rate for C-Trains is actually 10% and 20% greater than the mean for A-Trains when the overall data is tested, and 10%, 20%, and 30% greater when only looking at stability-related data. These differences are also consistent with those observed (without significance) in the actual data currently available. Note that the 10% column for the overall data and the 30% column for the stability-related only data are the appropriate ones for making "best estimates" because they are consistent with the results based on pooled data for the 4 years.

TABLE 5.5

POWER OF HYPOTHESIS TESTS USING OVERALL DATA

(entries are probabilities of detecting a significant effect at the 95% level)

| #YEARS | PERCENT INCREASE IN C RATES OVER A RATES | |
|---|---|---|
| | 10% | 20% |
| 4 | 15 | 34 |
| 8 | 22 | 54 |
| 12 | 28 | 68 |
| 15 | 32 | 77 |

TABLE 5.6

POWER OF HYPOTHESIS TESTS USING STABILITY-RELATED DATA ONLY

(entries are probabilities of detecting a significant effect at the 95% level)

| #YEARS | PERCENT INCREASE IN C RATES OVER A RATES | | |
|---|---|---|---|
| | 10% | 20% | 30% |
| 4 | 10 | 17 | 27 |
| 8 | 12 | 25 | 43 |
| 12 | 15 | 32 | 56 |
| 15 | 16 | 37 | 64 |

Note: The above analysis uses the fleet data as a basis. In this case, C-Trains were found to have higher average accident rates than A-Trains. This may be contrary to what was expected. A similar analysis could be undertaken assuming A-Trains to have a higher average accident rate than C-Trains. Identical sample size requirements would be required.

## 5.10 Summary

The various train types may cause significant differences in accident rates, but for A and C-Trains much of the impacts do not appear to be due to issues of stability. Instead, the different usage patterns of different types of trucks also appear to be very important determinants of the relative safety of different types of truck configurations. Only much larger data samples will permit any existing stability differences between A and C-Trains to be identified with statistical significance using the univariate tests. Although a multivariate analysis may improve the ability to detect such a difference, this also would require data on many additional variables that are not readily available.

## Chapter 6: Summary and Conclusions

Great care must be taken in drawing general conclusions from a study of this nature. Analysis of accident rates in general and comparisons in particular are fraught with problems. In this context, the information presented here must be considered as "circumstantial evidence" as opposed to "unquestioned" fact.

In collecting the data and undertaking the analysis, every attempt has been made to be objective. This is tempered, however, by the fact that judgement had to be used in some cases (for example, when assembling data from accident report files to summary sheets).

With the above as background, the following observations are offered:

1) Articulated trucks are to be over-represented in the total accidents in Saskatchewan relative to their proportion of the total number of vehicles.

2) Accidents involving articulated trucks have a disproportionate number of fatalities relative to other vehicle types.

3) The majority of large truck accidents, in particular, injury and fatal accidents occur in rural areas.

4) Driver condition and environmental factors are the major contributing factors in articulated truck accidents.

5) Given that large trucks typically travel more than other vehicles, it is reasonable to use exposure as a parameter in measuring and comparing accident experience of different vehicle types.

6) Exposure generally, but exposure of articulated trucks in particular, is very difficult to estimate accurately on a system wide basis because of the limitations in the available data. Major limitations exist in terms of vehicle classification data. Because of these limitations, there are substantial uncertainties inherent in system determined accident rates.

7) Fleet specific accident experience indicates an overall over-the-road accident rate of 1.22 accidents per million km for five fleets operating articulated trucks over 586 million kms during the 1983-86 period. When adjusted for differences in the definition of an accident and highway and rural road travel, the accident rates of the five fleets

are in the order of .64 accidents per million vehicle km. This is comparable to the accident rate of all vehicles operating on provincial highways in Saskatchewan.

8) Double trailer units operated by the five fleets throughout Western Canada appear to have an accident rate somewhat lower than single unit trailers. This difference however appears attributable to differences in usage patterns of the two vehicle types rather than the inherent stability characteristics of the two types of vehicles.

9) B-Trains appear to have a lower accident rate than either A or C-Train configurations. A and C-Trains do not appear to display significant differences in their stability risks, but there is some evidence that C-Trains may result in more serious accidents than A-Trains.

10) During the course of the study, there were no obvious major inadequacies identified related to the safety of large trucks operating in Saskatchewan. Most large truck accidents are, like accidents involving other vehicle types, caused by a combination of driver error, environmental

conditions and chance circumstance. As such, there are no apparent "easy quick-fix" solutions to accidents involving large trucks. This is however not to suggest that continued vigilance is not required. Rather, it suggests that the fleet operators that assisted in this study take safety as a very serious matter and as a result, have a safety record at least comparable to that of the vehicle population in total. Further, because of a job well done to date, future improvements in large truck safety are likely to be marginal improvements. That is, there is unlikely to be any ways identified to dramatically improve an already respectable safety record.

11) Items 1-6 (at least) are common themes of many other studies and in this respect, Saskatchewan has no different truck accident experience than other jurisdictions where similar studies have been conducted.

## Chapter 7: Suggestions for Further Research

This project attempted to quantify and compare the accident experience of large trucks operating in Saskatchewan with large trucks operating in other jurisdictions and other vehicles operating in Saskatchewan. This has in part been accomplished, however the limitations of available data combined with the complexity of the required analysis made it impossible to fully accomplish this overall objective. In this context, it is possible to identify other research that could be undertaken. This includes the following:

### 1. C-Train Performance

It had been anticipated that the safety experience for C-Trains would be found to be better than that for A-Trains. While this was not found to be the case, an explanation for why not was not possible. It is therefore recommended that further effort be directed to the detailed analysis of the over-the-road performance of C-Trains. The most productive next step would be a detailed analysis of past C-Train accidents plus detailed follow-up and discussions with fleet maintenance managers, mechanics and drivers. In this context, some early C-dollies had axle steering properties that are now considered undesirable and generally have disappeared. The configuration was also new in the early-mid 80's and a higher accident rate might have been expected until the

experience with the configuration matured.

2. Multivariate Analysis

This, as well as previous studies related to the accident experience of large trucks, has identified the limitation of univariate statistical tests in identifying and explaining variations in accident experience between vehicle types, vehicle configurations, etc. There are numerous variables other than vehicle type and configuration that affect accident experience. These other variables are in effect assumed to be nonexistent or unimportant in an univariate analysis and as a result the usefulness of the univariate analysis is seriously limited. On the other hand, the data demands of a meaningful multivariate analysis far exceeds currently available data. It is clear however that the multivariate approach is required if significant progress related to explaining differences in accident experience is to be made. This multivariate analysis would however be a major undertaking. It is therefore recommended that the practicality of undertaking a meaningful multivariate analysis be explored. (Note: This multivariate analysis methodology would be very useful in the study in all types of vehicle accidents, not only those associated only with large trucks.)

3. Vehicle Classification Data

The limitations of existing data base information, in particular that related to vehicle classification, was identified as a weak link during the course of this project. The inherent problem was that the database information was not assembled or intended to be used for the detailed purposes for which it was used within the context of this project. The use (or misuse) of this database information for detailed purposes similar to those in this study is (unfortunately) common practice in highway planning and analysis. It is therefore recommended that alternatives available to improve the quality and reliability of information included in highway database be explored so as to make this type of information more compatible for use in specific detailed analysis similar to this project. This would in essence involve the determination of the number of locations and the type of information required at specific locations in the highway network so as to provide more reliable detailed statistics on vehicles by type.

4. Large Truck Accidents in Perspective

While safety performance of large trucks is often cited by the public as a serious concern, the results of this study (as well as others) indicate that the accident rate of large trucks may not be the most pressing highway safety problem. There would therefore

appear to be a need to identify systematically and quantify the full range of highway safety issues and to put each in its' proper perspective. This type of analysis would help the general public appreciate the issues and it would in turn be of assistance to highway agencies in targeting programs and allocating resources. To illustrate, articulated trucks are involved in about 20 fatal accidents per year in Saskatchewan. Many or most of these fatalities involve errors by drivers, environmental factors or other variables that have nothing to do with type or configuration of large trucks. Many of the serious accidents involving large trucks result because of errors in judgement, etc. made by drivers of vehicles other than the large trucks. That is, other drivers run into the rear end of large trucks, for example. As a result a safety policy or program specifically targeted to issues of large truck type or configuration would be expected to have little impact upon the number of highway fatalities per year in Saskatchewan. On the other hand, alcohol is associated with over half the 200-300 fatalities each year on highways in Saskatchewan. As such, if the objective is to reduce fatalities on Saskatchewan highways, it is more likely to be effective to allocate scarce program dollars to the issue of drunk driving than to the safety of various types and configurations of large trucks.

While this type of information is common knowledge within highway agencies, it is not common knowledge among the public. There is therefore a need to put highway safety issues in proper

perspective and to communicate these facts effectively and aggressively to the general public.

# APPENDIX

## DETAILS OF STATISTICAL TESTING

DETAILED CALCULATIONS OF STATISTICAL TESTS

The following tables provide the basis for the summary results in the draft chapter on the statistical analysis of large truck accidents. Tables 1 through 4 of the draft chapter are based on a comparison of sample means taken from the spreadsheets of "verified" raw data. The first spreadsheet includes all accidents and the second contains only the stability-related data.

I did make one adjustment to the spreadsheet raw data before taking the difference of means. The Lotus 1-2-3 program's function for variance deviations from the mean is divided by n, the sample size. An unbiased estimator that is useful for small sample sizes is to divide by (n-1). I corrected all of the variance values in the spreadsheet by the factor n/(n-1).

In the tables below, "delta means" refers to the difference between the means for the samples being compared, which are provided in the first two columns. "Delta sigma" refers to the square root of the sum of the variances of the two in the preceding columns, divided by the sample size (typically 4 years). The t-statistic is equal to the ratio of delta means to delta sigma. The final column is the confidence level with which the t-statistic implies that we can reject the hypothesis that the difference in means is equal to zero. Because of a priori, we cannot say whether the difference will be larger or smaller than zero if it is not equal to zero (the confidence levels are based on a two-tailed hypothesis test).

STATISTICAL TESTS

TABLE 1 SUPPLEMENT: SINGLES VERSUS DOUBLES

| | | SINGLES | DOUBLES | PERCENT DIFF. | delta mean | delta sigma | t-stat | confidence level (%) |
|---|---|---|---|---|---|---|---|---|
| **ALL ACCIDENTS** | | | | | | | | |
| CARRIER 1 | - mean | 1.862 | 0.803 | 2.32 | 1.059 | 0.246 | 4.30 | >99.9 |
| | - var | 0.227 | 0.016 | | | | | |
| CARRIER 2 | - mean | 0.973 | 1.185 | 1.22 | -0.212 | 0.164 | 1.29 | 80 |
| | - var | 0.097 | 0.011 | | | | | |
| POOLED | - mean | 1.697 | 0.904 | 1.88 | 0.793 | 0.190 | 4.18 | >99.9 |
| | - var | 0.138 | 0.006 | | | | | |
| **STABILITY RELATED ACCIDENTS** | | | | | | | | |
| CARRIER 1 | - mean | 0.599 | 0.319 | 1.88 | 0.28 | 0.140 | 2.01 | 96 |
| | - var | 0.071 | 0.007 | | | | | |
| CARRIER 2 | - mean | 0.473 | 0.585 | 1.24 | -0.112 | 0.176 | 0.64 | 48 |
| | - var | 0.114 | 0.010 | | | | | |
| POOLED | - mean | 0.573 | 0.390 | 1.47 | 0.183 | 0.108 | 1.69 | 91 |
| | - var | 0.039 | 0.008 | | | | | |

TABLE 2 SUPPLEMENT: B-TRAINS VERSUS C-TRAINS

| | | B-TRAINS | C-TRAINS | PERCENT DIFF. | delta mean | delta sigma | t-stat | confidence level (%) |
|---|---|---|---|---|---|---|---|---|
| **ALL ACCIDENTS** | | | | | | | | |
| CARRIER 1 | - mean | 0.759 | 1.766 | 2.33 | -1.007 | 0.619 | 1.63 | 90 |
| | - var | 0.082 | 1.453 | | | | | |
| CARRIER 2 | - mean | 0.961 | 0.826 | 1.16 | 0.135 | 0.288 | 0.47 | 36 |
| | - var | 0.107 | 0.224 | | | | | |
| POOLED | - mean | 0.811 | 0.948 | 1.17 | -0.137 | 0.151 | 0.91 | 64 |
| | - var | 0.035 | 0.056 | | | | | |
| **STABILITY RELATED ACCIDENTS** | | | | | | | | |
| CARRIER 1 | - mean | 0.180 | 0.363 | 2.02 | -0.183 | 0.222 | 0.82 | 59 |
| | - var | 0.023 | 0.175 | | | | | |
| CARRIER 2 | - mean | 0.318 | 0.572 | 1.80 | -0.254 | 0.147 | 1.73 | 92 |
| | - var | 0.003 | 0.083 | | | | | |
| POOLED | - mean | 0.217 | 0.505 | 2.33 | -0.288 | 0.127 | 2.26 | 98 |
| | - var | 0.012 | 0.053 | | | | | |

TABLE 3 SUPPLEMENT: A-TRAINS VERSUS C-TRAINS

| | | A-TRAINS | C-TRAINS | PERCENT DIFF. | delta mean | delta sigma | t-stat | confidence level (%) |
|---|---|---|---|---|---|---|---|---|
| **ALL ACCIDENTS** | | | | | | | | |
| CARRIER 1 | - mean | 0.674 | 1.766 | 2.62 | -1.092 | 0.607 | 1.80 | 93 |
| | - var | 0.023 | 1.453 | | | | | |
| CARRIER 2 | - mean | 1.466 | 0.826 | 1.77 | 0.64 | 0.282 | 2.27 | 98 |
| | - var | 0.095 | 0.224 | | | | | |
| POOLED | - mean | 0.842 | 0.948 | 1.13 | -0.106 | 0.137 | 0.77 | 56 |
| | - var | 0.019 | 0.056 | | | | | |
| **STABILITY RELATED ACCIDENTS** | | | | | | | | |
| CARRIER 1 | - mean | 0.343 | 0.363 | 1.06 | -0.02 | 0.213 | 0.09 | 7 |
| | - var | 0.007 | 0.175 | | | | | |
| CARRIER 2 | - mean | 0.855 | 0.572 | 1.49 | 0.283 | 0.239 | 1.19 | 77 |
| | - var | 0.145 | 0.083 | | | | | |
| POOLED | - mean | 0.451 | 0.505 | 1.12 | -0.054 | 0.131 | 0.41 | 32 |
| | - var | 0.016 | 0.053 | | | | | |

TABLE 4 SUPPLEMENT: A-TRAINS VERSUS B-TRAINS

| | | A-TRAINS | B-TRAINS | PERCENT DIFF. | delta mean | delta sigma | t-stat | confidence level (%) |
|---|---|---|---|---|---|---|---|---|
| **ALL ACCIDENTS** | | | | | | | | |
| CARRIER 1 | - mean | 0.674 | 0.759 | 1.13 | -0.085 | 0.162 | 0.52 | 40 |
| | - var | 0.023 | 0.082 | | | | | |
| CARRIER 2 | - mean | 1.466 | 0.961 | 1.53 | 0.505 | 0.225 | 2.25 | 98 |
| | - var | 0.095 | 0.107 | | | | | |
| POOLED | - mean | 0.842 | 0.811 | 1.04 | 0.031 | 0.116 | 0.27 | 21 |
| | - var | 0.019 | 0.035 | | | | | |
| **STABILITY RELATED ACCIDENTS** | | | | | | | | |
| CARRIER 1 | - mean | 0.343 | 0.180 | 1.91 | 0.163 | 0.087 | 1.88 | 94 |
| | - var | 0.007 | 0.023 | | | | | |
| CARRIER 2 | - mean | 0.855 | 0.318 | 2.69 | 0.537 | 0.192 | 2.79 | 99.5 |
| | - var | 0.145 | 0.003 | | | | | |
| POOLED | - mean | 0.451 | 0.217 | 2.08 | 0.234 | 0.084 | 2.80 | 99.5 |
| | - var | 0.016 | 0.012 | | | | | |

SUPPLEMENT FOR INTER-CARRIER COMPARISON

| | | CARRIER 1 | CARRIER 2 | PERCENT DIFF. | delta mean | delta sigma | t-stat | confidence level (%) |
|---|---|---|---|---|---|---|---|---|
| **ALL ACCIDENTS** | | | | | | | | |
| SINGLE ACCIDENTS | - mean | 1.862 | 0.973 | 1.91 | 0.889 | 0.285 | 3.12 | 99.9 |
| | - var | 0.227 | 0.097 | | | | | |
| DOUBLE ACCIDENTS | - mean | 0.803 | 1.185 | 1.48 | -0.382 | 0.082 | 4.65 | >99.9 |
| | - var | 0.016 | 0.011 | | | | | |
| ALL ACCIDENTS | - mean | 1.187 | 1.245 | 1.05 | -0.058 | 0.116 | 0.50 | 38 |
| | - var | 0.046 | 0.084 | | | | | |
| **STABILITY RELATED ACCIDENTS** | | | | | | | | |
| SINGLE ACCIDENTS | - mean | 0.599 | 0.473 | 1.27 | 0.126 | 0.215 | 0.59 | 44 |
| | - var | 0.071 | 0.114 | | | | | |
| DOUBLE ACCIDENTS | - mean | 0.319 | 0.585 | 1.83 | -0.266 | 0.065 | 4.08 | >99.9 |
| | - var | 0.007 | 0.010 | | | | | |
| ALL ACCIDENTS | - mean | 0.419 | 0.555 | 1.32 | -0.136 | 0.071 | 1.92 | 95 |
| | - var | 0.016 | 0.084 | | | | | |

SUPPLEMENT FOR CHI-SQUARE TESTS

These tests reequire the development of matrices that categorize the data. For instance, to assess whether the risk of property damage is independent of the type of the train, the numbers of all accidents for each train type are divided into those with damages and those without. This creates six categories. A chi-squared value is calculated from such a table by comparing the numbers to those that would be expected if the two dimensions were in fact not dependent. As with the t-tests, the chi-squared value can be used to determine the confidence level with which we can reject the hypothesis that the truck type does not affect each measure of accident severity. The table below lists the numbers of accidents in each category for each chi-squared test I performed, the calculated chi-squared value and the confidence level for rejecting the hypothesis of independence. For a matrix m by n, the degrees of freedom needed to calculate these confidence levels are (m-1)x(n-1).

SUPPLEMENT FOR CHI-SQUARE TESTS - 3A

CHI-SQUARE TESTS FOR PROPERTY DAMAGE BY CARRIER

CARRIER 1 ALL ACCIDENTS

| | SINGLES | | DOUBLES | | Total | Chi-Square | Confidence level that effect exists |
|---|---|---|---|---|---|---|---|
| | Actual | Expected | Actual | Expected | | | |
| No Property damage | 46 | 42.99 | 35 | 38.01 | 81 | 0.56 | 57 |
| Property damage | 170 | 173.01 | 156 | 152.99 | 326 | | |
| Total | 216 | | 191 | | 407 | | |

| | A-TRAIN | | B-TRAIN | | C-TRAIN | | Total | Chi-Square | Confidence level that effect exists |
|---|---|---|---|---|---|---|---|---|---|
| | Actual | Expected | Actual | Expected | Actual | Expected | | | |
| No Property damage | 21 | 18.30 | 10 | 13.68 | 4 | 3.02 | 35 | 2.14 | 57 |
| Property damage | 70 | 72.70 | 58 | 54.32 | 11 | 11.98 | 139 | | |
| Total | 91 | | 68 | | 15 | | 174 | | |

CARRIER 1 STABILITY RELATED ACCIDENTS

| | SINGLES | | DOUBLES | | Total | Chi-Square | Confidence level that effect exists |
|---|---|---|---|---|---|---|---|
| | Actual | Expected | Actual | Expected | | | |
| No Property damage | 19 | 16.78 | 16 | 18.22 | 35 | 0.74 | 59 |
| Property damage | 51 | 53.22 | 60 | 57.78 | 111 | | |
| Total | 70 | | 76 | | 146 | | |

| | A-TRAIN | | B-TRAIN | | C-TRAIN | | Total | Chi-Square | Confidence level that effect exists |
|---|---|---|---|---|---|---|---|---|---|
| | Actual | Expected | Actual | Expected | Actual | Expected | | | |
| No Property damage | 11 | 10.00 | 4 | 3.48 | 0 | 1.52 | 15 | 2.17 | 63 |
| Property damage | 35 | 36.00 | 12 | 12.52 | 7 | 5.48 | 54 | | |
| Total | 46 | | 16 | | 7 | | 69 | | |

CARRIER 2 ALL ACCIDENTS

| | SINGLES | | DOUBLES | | Total | Chi-Square | Confidence level that effect exists |
|---|---|---|---|---|---|---|---|
| | Actual | Expected | Actual | Expected | | | |
| No Property damage | 5 | 5.69 | 23 | 22.31 | 28 | 0.13 | 27 |
| Property damage | 21 | 20.31 | 79 | 79.69 | 100 | | |
| Total | 26 | | 102 | | 128 | | |

| | A-TRAIN | | B-TRAIN | | C-TRAIN | | Total | Chi-Square | Confidence level that effect exists |
|---|---|---|---|---|---|---|---|---|---|
| | Actual | Expected | Actual | Expected | Actual | Expected | | | |
| No Property damage | 13 | 11.13 | 3 | 6.93 | 5 | 2.94 | 21 | 5.05 | 92 |
| Property damage | 40 | 41.87 | 30 | 26.07 | 9 | 11.06 | 79 | | |
| Total | 53 | | 33 | | 14 | | 100 | | |

CARRIER 2 STABILITY RELATED ACCIDENTS

| | SINGLES Actual | SINGLES Expected | DOUBLES Actual | DOUBLES Expected | Total | Chi-Square | Confidence level that effect exists |
|---|---|---|---|---|---|---|---|
| No Property damage | 5 | 2.86 | 10 | 12.14 | 15 | 2.61 | 90 |
| Property damage | 7 | 9.14 | 41 | 38.86 | 48 | | |
| Total | 12 | | 51 | | 63 | | |

| | A-TRAIN Actual | A-TRAIN Expected | B-TRAIN Actual | B-TRAIN Expected | C-TRAIN Actual | C-TRAIN Expected | Total | Chi-Square | Confidence level that effect exists |
|---|---|---|---|---|---|---|---|---|---|
| No Property damage | 6 | 6.08 | 0 | 2.16 | 4 | 1.76 | 10 | 6.21 | 96 |
| Property damage | 25 | 24.92 | 11 | 8.84 | 5 | 7.24 | 41 | | |
| Total | 31 | | 11 | | 9 | | 51 | | |

CHI-SQUARE TESTS FOR PROPERTY DAMAGE POOLED RESULTS

POOLED - ALL ACCIDENTS

| | SINGLES Actual | SINGLES Expected | DOUBLES Actual | DOUBLES Expected | Total | Chi-Square | Confidence level that effect exists |
|---|---|---|---|---|---|---|---|
| No Property damage | 51 | 49.30 | 58 | 59.70 | 109 | 0.13 | 27 |
| Property damage | 191 | 192.70 | 235 | 233.30 | 426 | | |
| Total | 242 | | 293 | | 535 | | |

| | A-TRAIN Actual | A-TRAIN Expected | B-TRAIN Actual | B-TRAIN Expected | C-TRAIN Actual | C-TRAIN Expected | Total | Chi-Square | Confidence level that effect exists |
|---|---|---|---|---|---|---|---|---|---|
| No Property damage | 26 | 22.74 | 13 | 19.63 | 9 | 5.64 | 48 | 5.85 | 94 |
| Property damage | 91 | 94.26 | 88 | 81.37 | 20 | 23.36 | 199 | | |
| Total | 117 | | 101 | | 29 | | 247 | | |

POOLED - STABILITY RELATED ACCIDENTS

| | SINGLES Actual | SINGLES Expected | DOUBLES Actual | DOUBLES Expected | Total | Chi-Square | Confidence level that effect exists |
|---|---|---|---|---|---|---|---|
| No Property damage | 24 | 19.62 | 26 | 30.38 | 50 | 2.12 | 85 |
| Property damage | 58 | 62.38 | 101 | 96.62 | 159 | | |
| Total | 82 | | 127 | | 209 | | |

| | A-TRAIN Actual | A-TRAIN Expected | B-TRAIN Actual | B-TRAIN Expected | C-TRAIN Actual | C-TRAIN Expected | Total | Chi-Square | Confidence level that effect exists |
|---|---|---|---|---|---|---|---|---|---|
| No Property damage | 17 | 16.04 | 4 | 5.63 | 4 | 3.33 | 25 | 0.83 | 33 |
| Property damage | 60 | 60.96 | 23 | 21.38 | 12 | 12.67 | 95 | | |
| Total | 77 | | 27 | | 16 | | 120 | | |

SUPPLEMENT FOR CHI-SQUARE TESTS - 3B

CHI-SQUARE TESTS FOR INJURIES BY CARRIER

CARRIER 1 ALL ACCIDENTS

| | SINGLES Actual | SINGLES Expected | DOUBLES Actual | DOUBLES Expected | Total | Chi-Square | Confidence level that effect exists |
|---|---|---|---|---|---|---|---|
| No Injury | 189 | 189.46 | 168 | 167.54 | 357 | 0.02 | 11 |
| Injury | 27 | 26.54 | 23 | 23.46 | 50 | | |
| Total | 216 | | 191 | | 407 | | |

| | A-TRAIN Actual | A-TRAIN Expected | B-TRAIN Actual | B-TRAIN Expected | C-TRAIN Actual | C-TRAIN Expected | Total | Chi-Square | Confidence level that effect exists |
|---|---|---|---|---|---|---|---|---|---|
| No Injury | 78 | 78.97 | 61 | 59.01 | 12 | 13.02 | 151 | 1.20 | 44 |
| Injury | 13 | 12.03 | 7 | 8.99 | 3 | 1.98 | 23 | | |
| Total | 91 | | 68 | | 15 | | 174 | | |

CARRIER 1 STABILITY RELATED ACCIDENTS

| | SINGLES Actual | SINGLES Expected | DOUBLES Actual | DOUBLES Expected | Total | Chi-Square | Confidence level that effect exists |
|---|---|---|---|---|---|---|---|
| No Injury | 54 | 58.01 | 67 | 62.99 | 121 | 3.12 | 92 |
| Injury | 16 | 11.99 | 9 | 13.01 | 25 | | |
| Total | 70 | | 76 | | 146 | | |

| | A-TRAIN Actual | A-TRAIN Expected | B-TRAIN Actual | B-TRAIN Expected | C-TRAIN Actual | C-TRAIN Expected | Total | Chi-Square | Confidence level that effect exists |
|---|---|---|---|---|---|---|---|---|---|
| No Injury | 40 | 40.67 | 14 | 14.14 | 7 | 6.19 | 61 | 1.03 | 40 |
| Injury | 6 | 5.33 | 2 | 1.86 | 0 | 0.81 | 8 | | |
| Total | 46 | | 16 | | 7 | | 69 | | |

CARRIER 2 ALL ACCIDENTS

| | SINGLES Actual | SINGLES Expected | DOUBLES Actual | DOUBLES Expected | Total | Chi-Square | Confidence level that effect exists |
|---|---|---|---|---|---|---|---|
| No Injury | 21 | 21.53 | 85 | 84.47 | 106 | 0.10 | 7 |
| Injury | 5 | 4.47 | 17 | 17.53 | 22 | | |
| Total | 26 | | 102 | | 128 | | |

| | A-TRAIN Actual | A-TRAIN Expected | B-TRAIN Actual | B-TRAIN Expected | C-TRAIN Actual | C-TRAIN Expected | Total | Chi-Square | Confidence level that effect exists |
|---|---|---|---|---|---|---|---|---|---|
| No Injury | 43 | 43.99 | 30 | 27.39 | 10 | 11.62 | 83 | 2.92 | 73 |
| Injury | 10 | 9.01 | 3 | 5.61 | 4 | 2.38 | 17 | | |
| Total | 53 | | 33 | | 14 | | 100 | | |

CARRIER 2 STABILITY RELATED ACCIDENTS

| | SINGLES Actual | SINGLES Expected | DOUBLES Actual | DOUBLES Expected | Total | Chi-Square | Confidence level that effect exists |
|---|---|---|---|---|---|---|---|
| No Injury | 7 | 9.52 | 43 | 40.48 | 50 | 4.00 | 95 |
| Injury | 5 | 2.48 | 8 | 10.52 | 13 | | |
| Total | 12 | | 51 | | 63 | | |

| | A-TRAIN Actual | A-TRAIN Expected | B-TRAIN Actual | B-TRAIN Expected | C-TRAIN Actual | C-TRAIN Expected | Total | Chi-Square | Confidence level that effect exists |
|---|---|---|---|---|---|---|---|---|---|
| No Injury | 26 | 26.14 | 11 | 9.27 | 6 | 7.59 | 43 | 4.17 | 86 |
| Injury | 5 | 4.86 | 0 | 1.73 | 3 | 1.41 | 8 | | |
| Total | 31 | | 11 | | 9 | | 51 | | |

CHI-SQUARE TESTS FOR INJURIES, POOLED RESULTS

POOLED - ALL ACCIDENTS

| | SINGLES Actual | SINGLES Expected | DOUBLES Actual | DOUBLES Expected | Total | Chi-Square | Confidence level that effect exists |
|---|---|---|---|---|---|---|---|
| No Injury | 210 | 209.43 | 253 | 253.57 | 463 | 0.02 | 11 |
| Injury | 32 | 32.57 | 40 | 39.43 | 72 | | |
| Total | 242 | | 293 | | 535 | | |

| | A-TRAIN Actual | A-TRAIN Expected | B-TRAIN Actual | B-TRAIN Expected | C-TRAIN Actual | C-TRAIN Expected | Total | Chi-Square | Confidence level that effect exists |
|---|---|---|---|---|---|---|---|---|---|
| No Injury | 121 | 122.98 | 91 | 86.26 | 22 | 24.77 | 234 | 4.12 | 87 |
| Injury | 23 | 21.02 | 10 | 14.74 | 7 | 4.23 | 40 | | |
| Total | 144 | | 101 | | 29 | | 274 | | |

POOLED - STABILITY RELATED ACCIDENTS

| | SINGLES Actual | SINGLES Expected | DOUBLES Actual | DOUBLES Expected | Total | Chi-Square | Confidence level that effect exists |
|---|---|---|---|---|---|---|---|
| No Injury | 61 | 67.09 | 110 | 103.91 | 171 | 5.01 | 97 |
| Injury | 21 | 14.91 | 17 | 23.09 | 38 | | |
| Total | 82 | | 127 | | 209 | | |

| | A-TRAIN Actual | A-TRAIN Expected | B-TRAIN Actual | B-TRAIN Expected | C-TRAIN Actual | C-TRAIN Expected | Total | Chi-Square | Confidence level that effect exists |
|---|---|---|---|---|---|---|---|---|---|
| No Injury | 66 | 66.73 | 25 | 23.40 | 13 | 13.87 | 104 | 1.29 | 47 |
| Injury | 11 | 10.27 | 2 | 3.60 | 3 | 2.13 | 16 | | |
| Total | 77 | | 27 | | 16 | | 120 | | |

SUPPLEMENT FOR CHI-SQUARE TESTS - 3C

CHI-SQUARE TESTS FOR FATALITIES, BY CARRIER

CARRIER 1 ALL ACCIDENTS

| | SINGLES Actual | SINGLES Expected | DOUBLES Actual | DOUBLES Expected | Total | Chi-Square | Confidence level that effect exists |
|---|---|---|---|---|---|---|---|
| No Fatality | 209 | 210.16 | 187 | 185.84 | 396 | 0.51 | 51 |
| Fatality | 7 | 5.84 | 4 | 5.16 | 11 | | |
| Total | 216 | | 191 | | 407 | | |

| | A-TRAIN Actual | A-TRAIN Expected | B-TRAIN Actual | B-TRAIN Expected | C-TRAIN Actual | C-TRAIN Expected | Total | Chi-Square | Confidence level that effect exists |
|---|---|---|---|---|---|---|---|---|---|
| No Fatality | 88 | 88.91 | 68 | 66.44 | 14 | 14.66 | 170 | 3.28 | 80 |
| Fatality | 3 | 2.09 | 0 | 1.56 | 1 | 0.34 | 4 | | |
| Total | 91 | | 68 | | 15 | | 174 | | |

CARRIER 1 STABILITY RELATED ACCIDENTS

| | SINGLES Actual | SINGLES Expected | DOUBLES Actual | DOUBLES Expected | Total | Chi-Square | Confidence level that effect exists |
|---|---|---|---|---|---|---|---|
| No Fatality | 69 | 69.04 | 75 | 74.96 | 144 | 0.00 | <1 |
| Fatality | 1 | 0.96 | 1 | 1.04 | 2 | | |
| Total | 70 | | 76 | | 146 | | |

| | A-TRAIN Actual | A-TRAIN Expected | B-TRAIN Actual | B-TRAIN Expected | C-TRAIN Actual | C-TRAIN Expected | Total | Chi-Square | Confidence level that effect exists |
|---|---|---|---|---|---|---|---|---|---|
| No Fatality | 45 | 45.33 | 16 | 15.77 | 7 | 6.90 | 68 | 0.51 | 23 |
| Fatality | 1 | 0.67 | 0 | 0.23 | 0 | 0.10 | 1 | | |
| Total | 46 | | 16 | | 7 | | 69 | | |

CARRIER 2 ALL ACCIDENTS

| | SINGLES Actual | SINGLES Expected | DOUBLES Actual | DOUBLES Expected | Total | Chi-Square | Confidence level that effect exists |
|---|---|---|---|---|---|---|---|
| No Fatality | 26 | 25.19 | 98 | 98.81 | 124 | 1.05 | 67 |
| Fatality | 0 | 0.81 | 4 | 3.19 | 4 | | |
| Total | 26 | | 102 | | 128 | | |

| | A-TRAIN Actual | A-TRAIN Expected | B-TRAIN Actual | B-TRAIN Expected | C-TRAIN Actual | C-TRAIN Expected | Total | Chi-Square | Confidence level that effect exists |
|---|---|---|---|---|---|---|---|---|---|
| No Fatality | 50 | 50.88 | 33 | 31.68 | 13 | 13.44 | 96 | 2.12 | 57 |
| Fatality | 3 | 2.12 | 0 | 1.32 | 1 | 0.56 | 4 | | |
| Total | 53 | | 33 | | 14 | | 100 | | |

CARRIER 2 STABILITY RELATED ACCIDENTS

| | SINGLES Actual | SINGLES Expected | DOUBLES Actual | DOUBLES Expected | Total | Chi-Square | Confidence level that effect exists |
|---|---|---|---|---|---|---|---|
| No Fatality | 12 | 11.62 | 49 | 49.38 | 61 | 0.49 | 50 |
| Fatality | 0 | 0.38 | 2 | 1.62 | 2 | | |
| Total | 12 | | 51 | | 63 | | |

| | A-TRAIN Actual | A-TRAIN Expected | B-TRAIN Actual | B-TRAIN Expected | C-TRAIN Actual | C-TRAIN Expected | Total | Chi-Square | Confidence level that effect exists |
|---|---|---|---|---|---|---|---|---|---|
| No Fatality | 30 | 29.78 | 11 | 10.57 | 8 | 8.65 | 49 | 1.72 | 56 |
| Fatality | 1 | 1.22 | 0 | 0.43 | 1 | 0.35 | 2 | | |
| Total | 31 | | 11 | | 9 | | 51 | | |

CHI-SQUARE TESTS FOR FATALITIES, POOLED RESULTS

POOLED - ALL ACCIDENTS

| | SINGLES Actual | SINGLES Expected | DOUBLES Actual | DOUBLES Expected | Total | Chi-Square | Confidence level that effect exists |
|---|---|---|---|---|---|---|---|
| No Fatality | 235 | 235.21 | 285 | 284.79 | 520 | 0.01 | 8 |
| Fatality | 7 | 6.79 | 8 | 8.21 | 15 | | |
| Total | 242 | | 293 | | 535 | | |

| | A-TRAIN Actual | A-TRAIN Expected | B-TRAIN Actual | B-TRAIN Expected | C-TRAIN Actual | C-TRAIN Expected | Total | Chi-Square | Confidence level that effect exists |
|---|---|---|---|---|---|---|---|---|---|
| No Fatality | 138 | 139.80 | 101 | 98.05 | 27 | 28.15 | 266 | 5.45 | 93 |
| Fatality | 6 | 4.20 | 0 | 2.95 | 2 | 0.85 | 8 | | |
| Total | 144 | | 101 | | 29 | | 274 | | |

POOLED - STABILITY RELATED ACCIDENTS

| | SINGLES Actual | SINGLES Expected | DOUBLES Actual | DOUBLES Expected | Total | Chi-Square | Confidence level that effect exists |
|---|---|---|---|---|---|---|---|
| No Fatality | 81 | 80.43 | 124 | 124.57 | 205 | 0.35 | 40 |
| Fatality | 1 | 1.57 | 3 | 2.43 | 4 | | |
| Total | 82 | | 127 | | 209 | | |

| | A-TRAIN Actual | A-TRAIN Expected | B-TRAIN Actual | B-TRAIN Expected | C-TRAIN Actual | C-TRAIN Expected | Total | Chi-Square | Confidence level that effect exists |
|---|---|---|---|---|---|---|---|---|---|
| No Fatality | 75 | 75.08 | 27 | 26.33 | 15 | 15.60 | 117 | 1.62 | 55 |
| Fatality | 2 | 1.93 | 0 | 0.68 | 1 | 0.40 | 3 | | |
| Total | 77 | | 27 | | 16 | | 120 | | |

## DERIVATION OF SAMPLE SIZE EFFECTS

To determine the likelihood of detecting an actual effect in "noisy" data, we use the fact that the distribution of a sample mean is normally distributed, with a standard deviation equal to the universe standard deviation divided by the square root of the sample size. Thus, the difference of means test will involve smaller and smaller standard deviations as the sample size increases. For a given underlying difference between two processes such as A versus C-train accidents, and a given required confidence level, there is an increasing probability of detecting that difference with statistical significance as the sample size increases. This probability can be calculated from the tables of area under a normal curve.

Since we are interested in testing the hypothesis that C accident rates are higher than A accident rates, then a one-tailed test is used. The normal curve tables indicate that any difference in means that is more than 1.645 standard deviations away from zero would only occur 5 percent of the time due to randomness in the sampling process. This implies 95 percent confidence that the observed effect is significantly different from zero. To find the probability that a sample would actually produce this much of a difference, we use the normal curve tables again to find the area of the distribution of the difference of means that is to the right of this cut-off point, given the true underlying difference, and the standard error (which depends on the sample size). This probability is 1 minus the area to the left of that point, which is the probability associated with the Z value:

$$Z = (CV - \text{delta mean})/\text{delta sigma},$$

where CV is the cut-off value, delta mean is the assumed (expected) difference of means, and delta sigma is the standard deviation of the difference of means distribution defined in an earlier section.

The tables below provide the data used to make these calculations, summarized in Tables 5 and 6. From the discussion above it is clear that several assumptions are required to fill in these tables:

- All of the calculations are predicated on a required confidence level of 95 percent.
- The estimates of the actual mean for A-train accident rates are based on the data in Table 3: .451 for all stability-related accidents and .847 for all accidents.
- The estimates of standard deviations are also based on the variances observed in the data: .016 and .053 for stability-related data, for A and C-trains respectively; .019 and .056 respectively for all accident data.
- The sample size n is defined as years of data collected.

DERIVATION OF SAMPLE SIZE EFFECTS

SUPPLEMENT TO TABLE 5

(Actual mean rate for ALL A-Train accidents = 0.842 )
(Variance of A and C train accident rate data is 0.019 and 0.056, respectively)

ALL ACCIDENTS, 10 PERCENT DEFFERENCE IN TRUE MEANS

| n | delta mean | delta sigma | CV | Z | Prob of Significant Difference |
|---|---|---|---|---|---|
| 4 | 0.084 | 0.137 | 0.225 | 1.03 | 15 |
| 8 | 0.084 | 0.097 | 0.159 | 0.78 | 22 |
| 12 | 0.084 | 0.079 | 0.130 | 0.58 | 28 |
| 15 | 0.084 | 0.071 | 0.116 | 0.46 | 32 |

ALL ACCIDENTS, 20 PERCENT DEFFERENCE IN TRUE MEANS

| n | delta mean | delta sigma | CV | Z | Prob of Significant Difference |
|---|---|---|---|---|---|
| 4 | 0.168 | 0.137 | 0.225 | 0.42 | 34 |
| 8 | 0.168 | 0.097 | 0.159 | -0.09 | 54 |
| 12 | 0.168 | 0.079 | 0.130 | -0.48 | 68 |
| 15 | 0.168 | 0.071 | 0.116 | -0.73 | 77 |

SUPPLEMENT TO TABLE 6

(Actual mean rate for STABILITY RELATED A-Train accidents = 0.451.)
(Variance of A and C train accident rate data is 0.016 and 0.053, respectively)

STABILITY RELATED ACCIDENTS, 10 PERCENT DEFFERENCE IN TRUE MEANS

| n | delta mean | delta sigma | CV | Z | Prob of Significant Difference |
|---|---|---|---|---|---|
| 4 | 0.045 | 0.131 | 0.216 | 1.30 | 10 |
| 8 | 0.045 | 0.093 | 0.153 | 1.16 | 12 |
| 12 | 0.045 | 0.076 | 0.125 | 1.05 | 15 |
| 15 | 0.045 | 0.068 | 0.112 | 0.98 | 16 |

STABILITY RELATED ACCIDENTS, 20 PERCENT DEFFERENCE IN TRUE MEANS

| n | delta mean | delta sigma | CV | Z | Prob of Significant Difference |
|---|---|---|---|---|---|
| 4 | 0.090 | 0.131 | 0.216 | 0.96 | 17 |
| 8 | 0.090 | 0.093 | 0.153 | 0.68 | 25 |
| 12 | 0.090 | 0.076 | 0.125 | 0.46 | 32 |
| 15 | 0.090 | 0.068 | 0.112 | 0.32 | 37 |

STABILITY RELATED ACCIDENTS, 30 PERCENT DEFFERENCE IN TRUE MEANS

| n | delta mean | delta sigma | CV | Z | Prob of Significant Difference |
|---|---|---|---|---|---|
| 4 | 0.135 | 0.131 | 0.216 | 0.62 | 27 |
| 8 | 0.135 | 0.093 | 0.153 | 0.19 | 43 |
| 12 | 0.135 | 0.076 | 0.125 | -0.14 | 56 |
| 15 | 0.135 | 0.068 | 0.112 | -0.35 | 64 |

STATISTICAL CALCULATION OF POOLED DATA

SINGLES

| | 1983 | 1984 | 1985 | 1986 | AVG | VAR | VAR*N/N-1 |
|---|---|---|---|---|---|---|---|
| CARRIER 1 | 62 | 44 | 72 | 38 | | | |
| | 30.3 | 29.1 | 29.4 | 26.4 | | | |
| | 2.05 | 1.51 | 2.45 | 1.44 | 1.862 | 0.170 | 0.227 |
| CARRIER 2 | 10 | 5 | 4 | 7 | | | |
| | 8.68 | 6.7 | 5.91 | 5.31 | | | |
| | 1.15 | 0.75 | 0.68 | 1.32 | 0.973 | 0.073 | 0.097 |
| POOLED | 72 | 49 | 76 | 45 | | | |
| | 38.98 | 35.8 | 35.31 | 31.71 | | | |
| | 1.85 | 1.37 | 2.15 | 1.42 | 1.697 | 0.104 | 0.138 |

DOUBLES

| | 1983 | 1984 | 1985 | 1986 | AVG | VAR | VAR*N/N-1 |
|---|---|---|---|---|---|---|---|
| CARRIER 1 | 41 | 41 | 61 | 48 | | | |
| | 54.4 | 56.6 | 61.5 | 64.7 | | | |
| | 0.75 | 0.72 | 0.99 | 0.74 | 0.803 | 0.012 | 0.016 |
| CARRIER 2 | 26 | 24 | 26 | 26 | | | |
| | 19.72 | 20.2 | 24.29 | 22.39 | | | |
| | 1.32 | 1.19 | 1.07 | 1.16 | 1.185 | 0.008 | 0.011 |
| POOLED | 67 | 65 | 87 | 74 | | | |
| | 74.12 | 76.8 | 85.79 | 87.09 | | | |
| | 0.90 | 0.85 | 1.01 | 0.85 | 0.904 | 0.005 | 0.006 |

A TRAINS

| | 1983 | 1984 | 1985 | 1986 | AVG | VAR | VAR*N/N-1 |
|---|---|---|---|---|---|---|---|
| CARRIER 1 | 23 | 19 | 30 | 19 | | | |
| | 31.07 | 32.3 | 35.11 | 36.96 | | | |
| | 0.74 | 0.59 | 0.85 | 0.51 | 0.674 | 0.017 | 0.023 |
| CARRIER 2 | 13 | 16 | 13 | 11 | | | |
| | 8.88 | 8.5 | 9.47 | 9.6 | | | |
| | 1.46 | 1.88 | 1.37 | 1.15 | 1.466 | 0.071 | 0.095 |
| POOLED | 36 | 35 | 43 | 30 | | | |
| | 39.95 | 40.8 | 44.58 | 46.56 | | | |
| | 0.90 | 0.86 | 0.96 | 0.64 | 0.842 | 0.014 | 0.019 |

B TRAINS

| | 1983 | 1984 | 1985 | 1986 | AVG | VAR | VAR*N/N-1 |
|---|---|---|---|---|---|---|---|

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | CARRIER 1 | 12 | 11 | 22 | 23 | | | |
| | | 23.16 | 21.85 | 22.4 | 22.31 | | | |
| | | 0.52 | 0.50 | 0.98 | 1.03 | 0.759 | 0.062 | 0.082 |
| | CARRIER 2 | 12 | 6 | 8 | 7 | | | |
| | | 8.31 | 8.21 | 9.15 | 8.79 | | | |
| | | 1.44 | 0.73 | 0.87 | 0.80 | 0.961 | 0.080 | 0.107 |
| | POOLED | 24 | 17 | 30 | 30 | | | |
| | | 31.47 | 30.06 | 31.55 | 31.1 | | | |
| | | 0.76 | 0.57 | 0.95 | 0.96 | 0.811 | 0.026 | 0.035 |

C TRAINS

| | | 1983 | 1984 | 1985 | 1986 | AVG | VAR | VAR*N/N-1 |
|---|---|---|---|---|---|---|---|---|
| | CARRIER 1 | 1 | 3 | 5 | 6 | | | |
| | | 0.28 | 2.51 | 4.09 | 5.58 | | | |
| | | 3.57 | 1.20 | 1.22 | 1.08 | 1.766 | 1.089 | 1.453 |
| | CARRIER 2 | 1 | 2 | 5 | 6 | | | |
| | | 2.59 | 3.51 | 5.68 | 4.09 | | | |
| | | 0.39 | 0.57 | 0.88 | 1.47 | 0.826 | 0.168 | 0.224 |
| | POOLED | 2 | 5 | 10 | 12 | | | |
| | | 2.87 | 6.02 | 9.77 | 9.67 | | | |
| | | 0.70 | 0.83 | 1.02 | 1.24 | 0.948 | 0.042 | 0.056 |

## STATISTICAL CALCULATION OF POOLED DATA - STABILITY RELATED ACCIDENTS

SINGLES

| | 1983 | 1984 | 1985 | 1986 | AVG | VAR | VAR*N/N-1 |
|---|---|---|---|---|---|---|---|
| CARRIER 1 | 21 | 14 | 27 | 8 | | | |
| | 30.3 | 29.1 | 29.4 | 26.4 | | | |
| | 0.69 | 0.48 | 0.92 | 0.30 | 0.599 | 0.053 | 0.071 |
| CARRIER 2 | 4 | 1 | 2 | 5 | | | |
| | 8.68 | 6.7 | 5.91 | 5.31 | | | |
| | 0.46 | 0.15 | 0.34 | 0.94 | 0.473 | 0.086 | 0.114 |
| POOLED | 25 | 15 | 29 | 13 | | | |
| | 38.98 | 35.8 | 35.31 | 31.71 | | | |
| | 0.64 | 0.42 | 0.82 | 0.41 | 0.573 | 0.029 | 0.039 |

DOUBLES

| | 1983 | 1984 | 1985 | 1986 | AVG | VAR | VAR*N/N-1 |
|---|---|---|---|---|---|---|---|
| CARRIER 1 | 14 | 17 | 27 | 18 | | | |
| | 54.4 | 56.6 | 61.5 | 64.7 | | | |
| | 0.26 | 0.30 | 0.44 | 0.28 | 0.319 | 0.005 | 0.007 |
| CARRIER 2 | 10 | 13 | 17 | 11 | | | |
| | 19.72 | 20.2 | 24.29 | 22.39 | | | |
| | 0.51 | 0.64 | 0.70 | 0.49 | 0.585 | 0.008 | 0.010 |
| POOLED | 24 | 30 | 44 | 29 | | | |
| | 74.12 | 76.8 | 85.79 | 87.09 | | | |
| | 0.32 | 0.39 | 0.51 | 0.33 | 0.390 | 0.006 | 0.008 |

A TRAINS

| | 1983 | 1984 | 1985 | 1986 | AVG | VAR | VAR*N/N-1 |
|---|---|---|---|---|---|---|---|
| CARRIER 1 | 13 | 10 | 14 | 9 | | | |
| | 31.07 | 32.3 | 35.11 | 36.96 | | | |
| | 0.42 | 0.31 | 0.40 | 0.24 | 0.343 | 0.005 | 0.007 |
| CARRIER 2 | 6 | 9 | 12 | 4 | | | |
| | 8.88 | 8.5 | 9.47 | 9.6 | | | |
| | 0.68 | 1.06 | 1.27 | 0.42 | 0.855 | 0.109 | 0.145 |
| POOLED | 19 | 19 | 26 | 13 | | | |
| | 39.95 | 40.8 | 44.58 | 46.56 | | | |
| | 0.48 | 0.47 | 0.58 | 0.28 | 0.451 | 0.012 | 0.016 |

B TRAINS

| | 1983 | 1984 | 1985 | 1986 | AVG | VAR | VAR*N/N-1 |
|---|---|---|---|---|---|---|---|

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | CARRIER 1 | 0 | 3 | 8 | 5 | | | |
| | | 23.16 | 21.85 | 22.4 | 22.31 | | | |
| | | 0.00 | 0.14 | 0.36 | 0.22 | 0.180 | 0.017 | 0.023 |
| | CARRIER 2 | 3 | 2 | 3 | 3 | | | |
| | | 8.31 | 8.21 | 9.15 | 8.79 | | | |
| | | 0.36 | 0.24 | 0.33 | 0.34 | 0.318 | 0.002 | 0.003 |
| | POOLED | 3 | 5 | 11 | 8 | | | |
| | | 31.47 | 30.06 | 31.55 | 31.1 | | | |
| | | 0.10 | 0.17 | 0.35 | 0.26 | 0.217 | 0.009 | 0.012 |

C TRAINS

| | | 1983 | 1984 | 1985 | 1986 | AVG | VAR | VAR*N/N-1 |
|---|---|---|---|---|---|---|---|---|
| | CARRIER 1 | 0 | 0 | 3 | 4 | | | |
| | | 0.28 | 2.51 | 4.09 | 5.58 | | | |
| | | 0.00 | 0.00 | 0.73 | 0.72 | 0.363 | 0.132 | 0.175 |
| | CARRIER 2 | 1 | 2 | 2 | 4 | | | |
| | | 2.59 | 3.51 | 5.68 | 4.09 | | | |
| | | 0.39 | 0.57 | 0.35 | 0.98 | 0.572 | 0.062 | 0.083 |
| | POOLED | 1 | 2 | 5 | 8 | | | |
| | | 2.87 | 6.02 | 9.77 | 9.67 | | | |
| | | 0.35 | 0.33 | 0.51 | 0.83 | 0.505 | 0.040 | 0.053 |

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